ABSTRACT

Title of Thesis: IDENTIFYING PROBLEMATIC HYDRIC SOILS DERIVED FROM RED PARENT MATERIALS IN THE UNITED STATES

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Environmental Science and Technology

Hydric soils derived from some red parent materials are "problematic" to identify during wetland delineations because they resist redox-induced color changes. These (PRPM) soils can be identified using the F21 – Red Parent Material field indicator, but the distribution and cause of the phenomenon, remains uncertain. The objectives of this study were to identify locations where PRPM occurs for appropriate use of the F21 field indicator throughout the country, and to better understand why PRPM soils resist redox-induced color changes. We found that PRPM is associated with sedimentary, hematite-rich, "red bed" formations and the deposits derived from them. Guidance maps have been developed showing where use of F21 is appropriate to support hydric soil (and therefore wetland) delineations impacted by PRPM. We also demonstrated that the cause of PRPM appears to be related to larger crystallite sizes of hematite in PRPM soils.

IDENTIFYING PROBLEMATIC HYDRIC SOILS DERIVED FROM RED PARENT MATERIALS IN THE UNITED STATES

by

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Dedication

To my sister, for being my absolute best friend.

To my mother, for her unconditional love.

And to my grandmother, who passed before completion of this journey. I love and miss you very much.

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Chapter 1: Introduction

Wetlands are highly valued for the variety of their environmental functions and socio-economic services (e.g. flood control, wildlife habitat, recreation, etc.) that they provide. In the United States, more than half of the country's wetlands have been lost to land conversion for agriculture, urban development, etc. since early settlement. As a result, recent environmental regulations, such as the Clean Water Act (CWA), have been enacted to protect and prevent further loss of wetlands across the country.

In order to protect wetlands under the CWA, however, they must be first be identified and delineated using certain diagnostic environmental characteristics, including the presence of a hydric soil. Some soils, derived from certain red parent materials (referred to as PRPM soils herein), however, are difficult, or "problematic," to identify as hydric because they often lack the expression of hydromorphological features typically used to identify most hydric soils in the field. Previous research has demonstrated that the occurrence of these soils is widespread across the nation, and that these soils are resistant to redox-induced color changes (associated with the formation of hydric morphology) due to characteristics inherited from their parent materials. The fundamental cause of the phenomenon is, however, still uncertain.

In order to address this issue, the National Technical Committee for Hydric Soils (NTCHS) approved a special hydric soil field indicator, F21 – Red Parent Material, to aid in the identification of hydric soils (and therefore wetlands) impacted by problematic RPM nationwide. Currently, the morphological requirements of the indicator are relatively minimal (e.g. 7.5YR or redder colors, with 10% redoximorphic features as iron depletion and/or concentrations in combination), such that if applied in inappropriate settings, many red soils (that are not really so wet) could be incorrectly identified as hydric during wetland delineations. In addition to this, the F21 indicator lacks guidance on the specific kinds of parent materials (i.e. geological formations) that produce PRPM soils, and requires that soils be evaluated and "qualify" as problematic (i.e. demonstrate their resistance to redox-induced color changes) by having Color Change Propensity Index (CCPI) values less than 30. For these reasons, the occurrence and distribution of PRPM soils throughout the country, and the appropriate locations where the F21 – Red Parent Material hydric soil field indicator should be applied, is uncertain.

The overall objectives of this research project were to: 1) determine the occurrence and distribution of PRPM soils and their parent materials throughout the United States; 2) develop national and regional guidance maps to aid in the appropriate application of the F21 - Red Parent Material hydric soil field indicator; and 3) attempt to better understand why soils derived from problematic RPM resist the development of redox-induced color changes normally associated with hydric soils. Each of the following chapters (Chapters 2-4) in this document examines a portion of these overall objectives. Specifically, Chapter 2 provides background information and describes the previous research conducted on PRPM soils and their occurrence. Chapter 3 addresses objectives 1 and 2 by describing efforts to determine which groups of soils and parent materials qualify as problematic RPM using CCPI technology, and then from these data, create geospatial datasets and guidance maps for the appropriate application of the F21 – Red Parent Material field indicator, nationwide. Objective 3 is then addressed in Chapter 4 by exploring several possible explanations for the cause of why PRPM soils are actually resistant to the development of redox-induced color changes and why these soils, even when wet, do not develop the hydromorphological features typical of most hydric (wetland) soils. It is our hope that the results of this research will help to improve the identification, delineation, and understanding of federally-regulated wetlands impacted by problematic RPM across the nation.

Chapter 2: Review of the Literature[1]

Wetlands: Values, Losses, and Definitions

Wetlands are broadly described as transitional areas between terrestrial and aquatic ecosystems where saturation with water is the dominant factor determining the nature of substrate development and the types of plant and animal communities living within (Mitsch and Gosselink, 2007). While classified into many different types based on differences in the dominant characteristics of their hydrologic regimes, plant communities, etc. (Cowardin et al., 1979), wetlands are regarded as one of the world's most valuable ecosystems for the variety of functions and ecosystem services they provide. These functions and services include: sediment and nutrient retention, groundwater recharge, wildlife habitat, coastline and flooding protection, nutrient recycling, recreation, etc. (Mitsch and Gosselink, 2007). From these services, a global economic assessment of all wetland ecosystems on the planet have been valued at more than $3.4 billion per year (Brander and Schuyt, 2010).

Historically, however, wetlands have traditionally been perceived as wastelands or areas that hindered socio-economic growth and development. Beginning with the establishment of Colonial America during the 1600s and 1700s, wetlands were viewed as swampy lands that bred diseases, restricted overland travel, or impeded the production of food and fiber (Dahl and Allord, 1997). Thus, began the draining of wetlands for early settlement (Dahl and Allord, 1997). Western expansion from the 1800s to 1900s resulted in large-scale conversions of wetlands to farmland

[1] Sections of this chapter are to be published by the United States Army Corps of Engineers (USACE) Engineer Research and Development Center, Environmental Laboratory in a Technical Report designed for use in conjunction with procedures outlined in the USACE Wetland Delineation Manual (Environmental Laboratory, 1987) and associated Regional Supplements (Berkowitz, 2011; 2012).

performed, financed, and incentivized by state and federal governments to increase the amount land more suitable for agriculture (Dahl and Allord, 1997). Technological advancements and rapidly growing populations between 1900 and present day further fueled demands to drain, infill, and/or manipulate wetland ecosystems for agriculture, urban development, energy production, and/or water diversion purposes (Dahl and Allord, 1997; Dahl, 1990). By these means, it is estimated that 274 million acres of the original 392 million acres of wetlands that would become part of the conterminous United States were lost between 1780 and 1980 (Dahl, 1990).

Beginning in the early 1970's, a shift in the views towards wetlands began as a series of environmental concerns became a focal point in American politics. Public awareness and education about environmental issues increased dramatically, resulting in new legislation and government programs designed to protect and preserve the nation's natural resources, including wetlands. One such piece of legislation, passed in 1972, is the Federal Water Pollution Control Act, now known widely as the Clean Water Act (CWA) (Adler et al., 1993). With the Commerce Clause of the U.S. Constitution as its backbone, the objective of the CWA is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters" (33 U.S.C.A. § 1251(a), 1972). Later amendments to the CWA, passed in 1977, created Section 404 with the intent to "prevent the discharge of dredged or fill material" into "navigable waters" of the United States without a permit (Adler et al., 1993). While the CWA broadly defines "navigable waters" as "waters of the United States," a series of Supreme Court case decisions and regulations set forth by the United States Army Corps of Engineers (USACE) and the Environmental Protection Agency (EPA) further defined "navigable" waters to include wetlands due to hydrological connection (Moya and Fono, 2011). It is this legislation, and the USACE and EPA as the joint administrators of the Section 404 permit program, that are now the primary mechanism(s) for wetland protection in the United States at the federal level.

With the inclusion of Section 404, there became an immediate need for a regulatory definition of wetlands and a means to systematically identify them. During the mid-1970's, the United States Fish and Wildlife Service (USFWS) developed a scientific definition of wetlands for their National Wetland Inventory (NWI) program designed to identify, classify and map all of the Nation's wetland resources (Cowardin et al., 1979). From this program, the USFWS defines wetlands as:

> "… lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. For the purposes of this classification, wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes; (2) the substrate is predominantly undrained hydric soil; and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season of each year" (Cowardin et al., 1979).

Then, in 1982, the task force assigned to delineating the nation's federal wetlands, the USACE, adopted this scientific definition and published the current working regulatory definition of a wetland for use with Section 404 of the CWA as:

> "Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal

circumstances do support, a prevalence of vegetation typically adapted for life in saturated soils. Wetlands generally include swamps, marshes, bogs, and similar areas" (Environmental Laboratory, 1987).[2]

From these definitions, wetlands are now classified and delineated at the federal level by having all three diagnostic environmental parameters: 1) the presence of wetland hydrology (i.e. near surface, seasonally high water tables); 2) the presence of hydrophytic vegetation (i.e. water-loving plants); and 3) the presence of a hydric soil. Hydric soils are the focus of this document.

Hydric Soils and Field Indicators of Hydric Soils

The term "hydric soil" was first coined by Cowardin et al. (1979) in cooperation with the USFWS to complete their NWI program. While the term was not formally defined, the documents do indicate that a hydric soil is "predominantly undrained." Understanding that a formal definition was needed, the USFWS enlisted the help of the United States Department of Agriculture, Soil Conservation Service (USDA-NRCS)[3] to develop a definition that closely correlated with hydrophytic vegetation in developing NWI maps (Mausbach and Parker, 2001). In response, representatives from the USDA-NRCS, EPA, and USACE formed a task force of soil

[2] Following publication of the USACE definition of wetlands, the U.S. Congress requested that the National Resource Council (NRC) create a committee to assess the adequacy and validity of wetland definitions to apply to delineation manuals. To date, the NRC defines a wetland as "an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physicochemical, biotic, or anthropogenic factors have removed them, or prevented their development" (National Resource Council, 1995).

[3] The Soil Conservation Service's name was changed to the Natural Resource Conservation Service in 1994. The acronym "USDA-NRCS" will be used in reference to both.

scientists, USFWS biologists, and University experts, known as the National Technical Committee for Hydric Soils (NTCHS), to finalize a definition of a hydric soil published in 1985 (Mausbach and Parker, 2001). Since that time, the formal definition has been revised with improved scientific understanding, and is currently defined as:

> "…a soil that has formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part" (Federal Register, 1994).

Currently, the critical element of this definition is the presence of "anaerobic conditions," reflecting the environmental conditions required for hydric morphological development and characteristics used by wetland delineators to identify hydric soils in the field.

The morphological development of a hydric soil is driven by a multitude of biologically mediated processes. Central to these processes are microbes (bacteria and fungi) that perform metabolic oxidation-reduction reactions using organic matter as energy sources in the soil (Craft, 2000). In a typical oxygenated environment, soil microbes oxidize sources of carbon in organic matter for energy, reducing oxygen as the electron acceptor (Craft, 2000). When soils are completely saturated with water (like in wetlands), oxygen diffuses 10,000 times more slowly through this water than through air, and therefore the soil is quickly depleted of oxygen as an available electron acceptor (Reddy and DeLaune, 2008; Craft, 2000). The resulting condition is referred to as anaerobiosis (i.e. reducing conditions) (Craft, 2000), and results in two major morphological characteristics of hydric soils: organic matter accumulation and redoximorphic features more specifically known as “iron concentrations” and “iron depletions” (Vepraskas and Sprecher, 1997).

Organic Matter Accumulation

As previously noted, when soils become anaerobic, the microbial community shifts to favor organisms that utilize electron acceptors other than oxygen. Other electron acceptors currently known to be available to microbes for these processes are NO_3^-, Mn^{4+}, Fe^{3+}, SO_4^{2-}, CO_2, and H^+, each reduced in an ordered energy-yielding hierarchy (from NO_3^- to H^+) depending on the degree of anaerobiosis, the species of microbes present, and the element availabilities in the environment (Craft, 2000; Reddy and DeLaune, 2008; Vepraskas and Faulkner, 2000). The reactions associated with these anaerobic microbes and alternate electron acceptors, however, are much slower and yield less energy compared to those of aerobic conditions, resulting in lower organic matter decomposition rates (Reddy and DeLaune, 2008; Craft, 2000). This overall process thus leads to increased organic matter accumulation in hydric soils towards the surface where organic inputs are greatest, and are currently recognized as Histosols, histic epipedons, mucky mineral soil materials, and/or dark colored mineral surface horizons (mollic or umbric epipedons) in the Keys to Soil Taxonomy (Soil Survey Staff, USDA-NRCS, 2014).

Redoximorphic Features

Furthermore, color changes in lower subsurface horizons take place as a result of the reduction of Fe^{3+} compounds in the soil. Iron oxides and oxihydroxides (containing Fe^{3+}) represent the most abundant oxide minerals in soils. The most common of these iron oxide minerals in soils include goethite, hematite, lepidocrocite, maghemite, and ferrihydrite (Schwertmann, 1993). In aerobic environments, these iron oxides coat the surface of soil mineral grains, resulting in soil matrix colors that typically range in shades of yellow, orange, red, and brown (Schwertmann, 1993). The actual color of the soil, more specifically, depends on the type(s) of iron oxides present, the abundances of iron oxide minerals present, as well as the size of the iron oxide crystals (Schwertmann, 1993). In aerobic conditions, Fe^{3+} within these iron oxides is relatively insoluble and immobile in the soil profile, outside of very acidic conditions where the Fe^{3+} can be dissolved (Schwertmann, 1993; Schwertmann, 2008).

Under anaerobic conditions, however, soil microbes reduce Fe^{3+} to Fe^{2+} during the oxidation of organic matter. This results in the mobilization of Fe^{2+} into soil solution, where Fe^{2+} lacks visible color and can be translocated or completely leached from the soil profile (Vepraskas and Faulkner, 2000). When this occurs, the iron oxide coatings on soil mineral grains are removed, leaving the low-chroma/gray-colored silicate mineral grains as the primary pigmenting agent. In some cases, the uncoated soil mineral grains may have a greenish or bluish tinge (i.e. gleyed color) to them, attributed to the possible reduction of Fe^{3+} contained within the crystallographic structures of the soil mineral grains themselves (Vepraskas and Faulkner, 2000). It should also be noted that even during anaerobiosis, oxygen is never completely removed from the soil. In many cases, oxygen is present in the soil profile via root channels from hydrophytic vegetation, soil pores or peds inaccessible to microbes, and/or temporal variation in saturation between wet and dry periods (Mitsch and Gosselink, 2007; Vepraskas and Faulkner, 2000). These processes result in translocation, reorganization, and segregation of iron phases that can be seen in soil color patterns. These distributions or patterns of soil color (yellow, orange, brown, gray, etc.) produced during alternating or permanent periods of anaerobiosis are referred to as “redoximorphic features.” Oxidized (Fe^{3+}) forms are more specifically termed “iron concentrations” and uncoated soil mineral grains where oxidized (Fe^{3+}) forms have been reduced (to Fe^{2+}) are referred to more specifically as “iron depletions” (Vepraskas and Faulkner, 2000).

The morphological features described above are common or “typical” of most hydric soils, with varying degrees in expression depending on site-specific conditions (Figure 2.1).

Figure 2.1. *Soil profile with morphological features typical of most hydric soils. The dark color of the horizon immediately below the surface indicates the accumulation of organic matter from decelerated microbial decomposition. The redoximorphic features in the subsurface are further distinguished by the type and/or color of the iron phase observed in the soil as "iron depletions" and "iron concentrations."Redoximorphic features as iron depletions are zones of high-value, low-chroma color patterns (value 4 or more, chroma 2 or less), and indicate the processes of iron reduction where iron oxide coatings have been reduced into colorless forms under saturated conditions by microbes (leaving the light, gray-colored silicate mineral grains exposed). Subsurface horizons entirely dominated by high-value, low-chroma colors are referred to as "depleted matrices." Redoximorphic features as iron concentrations are zones of warm-color patterns (reds, yellows, oranges) that indicate the processes of iron oxidation where oxygen has re-entered the soil following saturation and establishment of reducing conditions via fluctuating water tables, plant roots, and/or soil pore linings. Both iron depletions and depleted matrices are evidence of seasonally-high water tables as the reduction of iron phases in the soil requires anaerobic conditions following saturation. Photo credit: Dr. Martin Rabenhorst, University of Maryland.*

These features and characteristics, when found at specific depths and abundances in relation to the soil surface, are referred to as "Field Indicators of Hydric Soils," approved and maintained by the NTCHS. These indicators are described in *Field Indicators of Hydric Soils in the United States: A Guide for Identifying and Delineating Hydric Soils* and are designed to be "proof positive" evidence that a given soil that meets these indicators also meets the hydric soil definition (Berkowitz and Sallee, 2011, USDA-NRCS, 2017a). Furthermore, indicators are is applied regionally to specific USDA-NRCS Land Resource Regions (LRRs) and Major Land Resource Areas (MLRAs), as well as the USACE's Regional Supplement Regions, defined by the USACE, USFWS, EPA and USDA-NRCS (Wakeley, 2002; Berkowitz, 2011; USDA-NRCS, 2017a; Vepraskas et al., 2000) (Figure 2.2).

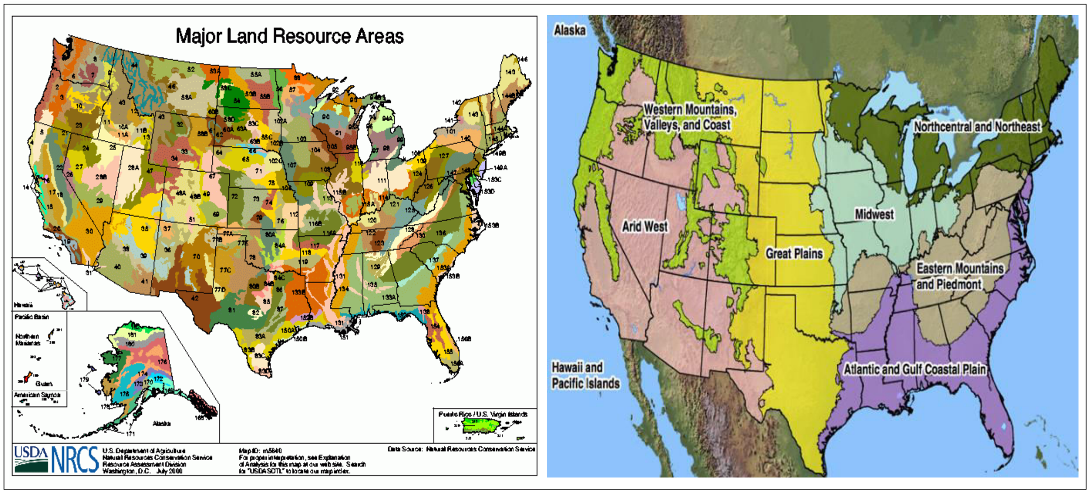

Figure 2.2. *USDA-Natural Resource Conservation Service's Major Land Resource map (left) (Resource Assessment Division, 2010) and the United States Army Corp of Engineers' Regional Supplement Regions map (right) (USACE, 2017). Field Indicators of Hydric Soils are applied regionally to these resource areas.*

More specific regional maps and supplements, generated by governmental agencies like the USDA-NRCS and USACE, are also provided to field personnel who perform wetland delineations to aid in the correct application of Field Indicators specific to their resource areas (Wakeley, 2002; USDA-NRCS, 2006; Berkowitz, 2011).

<u>Problematic Hydric Soils</u>

In some cases, however, there are soils that possess wetland hydrology (i.e. near surface, seasonally high water tables) required for anaerobiosis, but do not possess the "typical" hydromorphological features (i.e. Field Indicators) described above (Robinette et al., 2011). These soils are termed "problematic hydric soils," as they present challenging situations when assessing drainage and/or hydric status of a soil in the field. In most cases, this phenomenon is often caused by conditions that prevent iron reduction, and therefore interfere with the formation of redoximorphic features. Such situations may include: low iron content (lowering the availability of alternative electron acceptors to microbes); low organic carbon content and/or low soil temperature (decreasing the amount of microbial energy sources and overall biological activity); high oxygen contents (preventing the development of anaerobiosis); and high alkalinity (inhibiting reduction and translocation of iron in the soil) (Berkowitz and Sallee, 2011; Kuehl et al., 1997; Craft, 2000). These conditions have resulted in the identification of the following groups of problematic hydric soils:

1) Aquerts and aquertic soils (i.e. wet clay-rich soils) in which organic carbon is tightly bound to fine mineral particles and not available as an energy substrate for anaerobic bacteria (Jacob et al., 1997);
2) Aquasalids and other wet saline and alkaline soils where high salinity and alkalinity is detrimental to microbial activity or leads to nutrient deficiencies integral for microbial metabolism (Boettinger, 1997);
3) Gelisols (i.e. wet permafrost-affected soils) in which temperatures rarely exceed 5°C (the threshold considered as biological zero in the criteria of hydric soils), and thus inhibit overall microbial activity (Clark and Ping, 1997);
4) Aquods and psammaquents (i.e. wet sandy soils) that do not contain appreciable amounts of free iron in the soil to develop redoximorphic features (Kuehl et al., 1997);
5) Aquic andisols (i.e wet volcanic ash-rich soils) with oxyaquic conditions or the unique presence of Al-hydroxide coatings on iron oxides, thus preventing the microbial reduction of iron (McDaniel et al., 1997); and
6) historic or relict hydric soils that possess hydric morphology, but are no longer exhibit wetland hydrology (Robinette et al., 2011).

In other cases, problem soils are a result of properties of the soil itself and/or the soil's parent materials (Rabenhorst and Parikh, 2000; Elless et al., 1996). In many of these cases, soil colors or mineralogical properties of the soils (inherited from their parent materials) contribute to incorrect hydric determinations in these soils. The following groups of problematic hydric soils that represent these conditions are:

1) Aquolls and albolls (i.e. wet prairie soils) in which the dark colors of the organic-rich surface horizon(s) mask the presence of redoximorphic features (Bell and Richardson, 1997);
2) Green or bluish-colored, glauconite-rich or phyllitic soils in which colors from their mineralogy can be incorrectly confused with gleyed colors associated with extreme wetness (Robinette et al., 2011);
3) Anomalous, bright loamy and sandy soils in the Mid-Atlantic coastal plain where depleted matrices do not form and the soils remain "bright" (Robinette et al., 2011);
4) Soils derived from dark, gray-colored parent materials (e.g. black coal deposits, iron- and manganese-rich bedrock, horfels/burnt shales, etc.) where dark colors are confused with high organic contents and/or low-chroma colors associated with wetness are masked by the dark mineralogy (Stolt et al., 2001; Robinette et al., 2011);
5) Soils formed in limnic materials (i.e. marl soils and fine-earth deposits composed chiefly of cell walls of diatoms) that commonly exhibit light (value of 7 or 8) colors associated commonly with wetness (Robinette et al., 2011); and

6) Entisols and fluvaquents in flood plains of post-colonial settlement age believed too young to have developed predominant redox features (i.e. Piedmont Flood Plain Soils) (Lindbo, 1997).

Each of these problematic soils present challenging situations when identifying hydric soils (and therefore wetlands) in the field, and have led to the development of several Field Indicators specifically designed to address the previously stated phenomena (USDA-NRCS, 2017a, see “F19. Piedmont Flood Plain Soils,” “F20. Anomalous Bright Loamy Soils,” etc.).

Red Parent Material and Early Exploration for the Cause of Problematic Red Parent Material (PRPM) Hydric Soils

Another group of problematic hydric soils are red soils derived from certain red-colored parent materials (RPM) that develop relatively weak expressions of redoximorphic features (i.e. sometimes only iron concentrations/sometimes iron concentrations with small amounts of iron depletions) compared to most hydric soils in the field (referred to as PRPM soils herein) (Figure 2.3).

Figure 2.3. *Soil profile of a problematic hydric soil derived from Red Parent Material (RPM). Direct hydrologic and oxidation-reduction potential monitoring at this site confirms the presence of hydric soils. Compared to most hydric soils, this soil has weak expression of redoximorphic features as iron concentrations and/or depletions often used to delineate hydric soils (and therefore wetlands) in the field. (See Figure 2.1 for comparison). Soil profile is located in the Canaan Valley, WV. Photo credit: Dr. Martin Rabenhorst, University of Maryland.*

The earliest cases of this phenomenon were first explored in laboratory studies in which red soils were incubated under a variety of reducing conditions and monitored for changes in their soil color over time. In one such laboratory study, performed by Niroomand and Tedrow (1990), it was demonstrated that soil materials derived from dark red shales of the Triassic-aged, Brunswick formation were slower to develop gray, low-chroma colors than soil materials derived from the less red, Devonian-aged, Marcellus shale when incubated under reducing conditions with a D-glucose solution over a three-month period. In another study, Sprecher and Mokma (1989) examined glacially derived soil materials ranging in [Munsell] hue from 10YR to 5YR from MN, WI, and MI and also documented that the reddest materials (under reducing conditions) changed color more slowly. This slow development of redoximorphic features in these soils suggests that the iron oxide pigments responsible for soil color actually resist redox-induced color changes. When followed up with a field study, less expression of gray, low-chroma colored redoximorphic features was observed in soils with the reddest hues, even in low landscape positions where water tables were high (Mokma and Sprecher, 1994). They attributed the paucity of gray, low-chroma redox features to the presence of hematite in these soils (Mokma and Sprecher, 1994), while not specifying any particular mechanism for the phenomenon.

Working in the Culpeper basin of MD, Elless et al. (1996) also observed that wet soils derived from dark red, Triassic sedimentary rocks of the Gettysburg and New Oxford formations also showed less expression of gray, low-chroma redox depletions. Mineralogical analyses indicated that hematite was the only pigmenting iron oxide in the soils (Elless and Rabenhorst, 1994). It was suggested that the mechanism for the resistance of the soils to form gray, low-chroma depletions might be Al for Fe substitution in the hematite structure (Elless and Rabenhorst, 1994), since Al substitution had previously been shown to cause goethite to be less easily reduced in soils (Fey, 1983; Macedo and Bryant, 1987; 1989; Bryant and Macedo, 1990). Al for Fe substitution has also been shown to inhibit the reduction of hematite (as well as goethite) in laboratory studies (Cornell and Schwertmann, 2003), but no conclusive evidence has been presented to confirm this mechanism as the cause for PRPM soils. No other investigation to determine the underlying cause for PRPM soils to resist redox-induced color changes has been conducted to date.

The TF2 – Red Parent Material Field Indicator

Since these early studies of PRPM soils, numerous other cases of their occurrence have been documented in regions across the United States. Among the areas are the Hartford Rift Basin and the Connecticut River Valley in New England (Ford, 2014), clayey alluvial deposits derived from Permian red beds in central LA (Rabenhorst and Parikh, 2000), glacio-lacustrine sediments on southern shores of Lake Superior in MN, glacio-lacustrine sediments on western shores of Lake

Michigan in WI (Petersen et al., 1967; Wheeler et al., 1999), among many others.[4] The earliest observations of these PRPM soils eventually led to the development of a special field indicator, TF2 – Red Parent Material, approved nationwide for testing in the wet soils derived from RPM in the mid-1990s (USDA-NRCS, 1998 p. 18). The TF2 – Red Parent Material field indicator reads:

> "In parent material with [Munsell] hue of 7.5YR or redder, a layer at least 10 cm (4 inches) thick with a matrix value and chroma of 4 or less and 2 percent or more redox depletions and/or redox concentrations occurring as soft masses and/or pore linings. The layer is entirely within 30 cm (12 inches) of the soil surface. The minimum thickness requirement is 5 cm (2 inches) if the layer is the mineral surface layer" (USDA-NRCS, 2010).[5]

While the TF2 "test" indicator was developed to aid in wetland determinations in red soils specifically resistant to color changes and the formation of redox features, the majority of red soils or soils that come from a red-colored parent material are not problematic and readily form hydromorphic features under wetland conditions (Rabenhorst and Parikh, 2000). For example, red soils derived from metabasaltic rocks high in ferromagnetic elements, or from red-colored fluviodeltaic sands, both

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[4] The previously stated occurrences of the RPM phenomena are the only instances published in the literature to date. However, many more anecdotal cases of the RPM phenomenon have been reported across the country by several practicing soil and/or wetland scientists (USDA-NRCS, USACE, etc.) (M.C. Rabenhorst & Jacob F. Berkowitz, personal communication, 2015).

[5] User notes for the TF2 indicator also provided examples of appropriate types of geologic materials from which these problem soils might be derived. These were mostly Mesozoic and Paleozoic-aged, red sedimentary rocks and materials derived from them, as well as some basic, igneous and metamorphic crystalline rocks (associated with the Congaree River and its floodplains) (USDA-NRCS, 1998). The indicator proved useful in delineating problematic red soils in New England, but its redox color requirements were ineffective at distinguishing problematic red soils from non-problematic red soils in other regions (M.C. Rabenhorst and M. Stolt, personal communication, 2015). The concern for the original TF2 indicator between New England and other areas was that too few redoximorphic features were required for indicator use, and that use of the indicator would include many non-hydric soils that do not meet the hydric definition for delineations outside of New England.

occurring in the Coastal Plain Province, do not exhibit a resistance to color change (Rabenhorst and Parikh, 2000), despite their red colors or the iron contents of their parent materials (often attributed to red colors in soils) (Sirkin, 1986; Schwertmann, 1993). Furthermore, red soils derived from Paleozoic-aged, metamorphic and paracrystalline rocks found in floodplains along the Congaree River in North and South Carolina also do not exhibit a resistance to color change, despite previous claims that these soils are PRPM (USDA-NRCS, 2010 p. 28). For this reason, the TF2 indicator (requiring that soils only be 7.5YR or redder and contain only 2% redox features as either concentrations and/or depletions) could be erroneously applied during hydric soil (and therefore wetland) determinations in the field across the country.

The Color Change Propensity Index (CCPI)

In an attempt to resolve this issue, Rabenhorst and Parikh (2000) developed a laboratory approach used to quantify how easily red soils will develop low-chroma, gray colors (i.e. redox depletions) under reducing conditions. In their study, red soils (both suspected and not suspected to be derived from problematic RPM) were collected and treated with sodium dithionite in various treatments under differing time periods and temperatures in laboratory settings.[6] Following treatment, [Munsell] soil color (hue, value, chroma) was measured on the soils using a digital colorimeter. From the changes in soil color between the different treatments, a numerical relationship was developed to distinguish between red soils that are inherently

[6] Soils used in this study were predominantly collected from the Piedmont, Valley and Ridge, and Coastal Plain Physiographic Provinces. Sodium dithionite, also known as sodium hydrosulfite ($NaHSO_3$), is a strong reducing chemical agent capable of reducing iron oxides in soils. The rates of chemical reactions are generally known to increase with temperature.

resistant to color change (i.e. problematic) and those that are not. This laboratory-based test and the associated numerical index is called the Color Change Propensity Index (CCPI).[7] Based on results from this study, the CCPI groups soils into three categories based on ranges of CCPI values calculated for the soils used in the experiment:

1) non-problematic (soils did not resist color change under reducing conditions) if CCPI values > 40;

2) problematic (soils resisted color change under reducing conditions) if CCPI < 30; and

3) an intermediate range with CCPI values between 30 and 40 in which problematic-non-problematic evaluation of soils should be done with scrutiny (Figure 2.4).

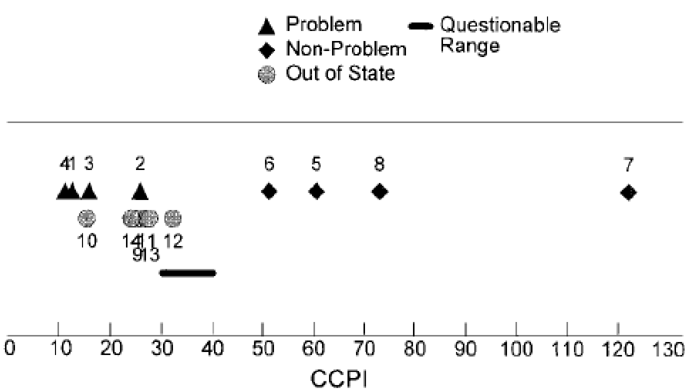

Figure 2.4. *Differentiation of problematic and non-problematic soils derived from potential Red Parent Materials (RPM) using Color Change Propensity Index (CCPI) values calculated in Rabenhorst and Parikh (2000). Figure 9 from Rabenhorst and Parikh (2000).*

Overall, this laboratory study resulted in a procedure that could quantitatively determine which red soils were problematic (i.e. resistant to color change) from those

[7] The equation is a composite of a hue index calculated using changes in Munsell hue and a chroma index based on changes in Munsell chroma. Munsell hue (officially notated as a combination of letters and numbers) was first converted to a numerical scale between 0 and 100 based on the hue measured for the soil before using the equation (Rabenhorst and Parikh, 2000).

that were not and would later be incorporated into a new field indicator to help identify PRPM soils in the field.

<u>The F21 – Red Parent Material Field Indicator and Obstacles to F21 Application</u>

Since the development of the CCPI, additional testing by the Mid-Atlantic Hydric Soils Committee (MAHSC)[8] led to the adoption of the current field indicator, F21 - Red Parent Material, approved for official use in MLRA 127 of LRR N, MLRA 145 of LRR R, MLRAs 147 and 148 of LRR S, and for testing in all soils derived from red parent materials across the country (USDA-NRCS, 2017a). This indicator essentially replaces the test indicator TF2. The F21 indicator reads:

> "A layer derived from red parent materials (see Glossary) that is at least 10 cm (4 inches) thick, starting at a depth ≤ 25 cm (10 inches) from the soil surface with a [Munsell] hue of 7.5YR or redder. The matrix has a value and chroma greater than 2 and less than or equal to 4. The layer must contain 10 percent or more depletions and/or distinct or prominent concentrations occurring a soft masses or pore linings. Redox depletions should differ in color by having:
>
> a. a minimum difference of one value higher and one chroma lower than the matrix, or

[8] The Mid-Atlantic Hydric Soils Committee (MAHSC) is a group of soil and wetland scientists from University communities, representatives from federal (USDA-NRCS, EPA, USACE, etc.), state (Departments of Natural Resources, etc.), local agencies, and the private sector. Members work together to pursue important research needs to better identify hydric soils in the field. In "testing" for the TF2 indicator, several suspected RPM sites in PA, WV, and MD were monitored for multiple years and assessed to meet the NTCHS "Hydric Soil Technical Standard" required for hydric designation. The testing at those sites resulted in more stringent redox color requirements for appropriate TF2 application, proposed to be incorporated into a new Field Indicator, F21. Additional information on the Hydric Soil Technical Standard can be found in the committee's Hydric Soil Technical Note 11, available on the USDA-NRCS website (*https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/use/hydric/*).

b. value of 4 or more and chroma of 2 or less" (USDA-NRCS, 2017a).[9]

Furthermore, the CCPI from Rabenhorst and Parikh (2000) was incorporated into the definition of "red parent material" in the User Notes of the F21 indicator, requiring that soils "be evaluated as problematic with CCPI values below 30" (USDA-NRCS, 2017a). Examples of geologic materials known to produce these soils have also been identified in the User Notes of the F21 indicator to guide appropriate application, such as "residuum in the Piedmont Province Triassic lowlands" or "Paleozoic 'red beds' of the Appalachian Mountains" (USDA-NRCS, 2017a).[10]

Despite these updates to the F21 field indicator, several obstacles still remain for correct application of the indicator by the average user. First, while most field indicators of hydric soils require a matrix chroma ≤ 2, F21 – Red Parent Material allows for inclusion red soils (7.5YR or redder) with chromas as high as 4 (USDA-NRCS, 2017a). Therefore, without prior knowledge and/or guidance regarding the soils in an area, the F21 – Red Parent Material indicator can be inappropriately applied to (better drained) red-colored soils not derived from problematic RPM (potentially resulting in erroneous identification of wetlands). Second, while the F21 User Notes identify a few examples of geologic materials confirmed as problematic RPM in the Mid-Atlantic regions, such guidance (e.g. a comprehensive list or glossary of confirmed [geologic] parent materials known to be problematic) is lacking

[9] While still requiring relatively little expression of redoximorphic features compared to other field indicators, F21 requires substantially more (10% vs 2%) redoximorphic features than did TF2.

[10] These parent materials were identified from the testing performed at field sites in the Piedmont Triassic lowlands and Appalachia regions by the MAHSC that resulted in the current version of the F21 – Red Parent Material field indicator.

throughout the rest of the country. Lastly, relatively few CCPI analyses have been previously performed on red soils suspected to be derived from problematic RPM. Thus, “CCPI values less than 30” (required for application of F21 – Red Parent Material) has not been confirmed broadly. For these reasons, the precise occurrence or distribution of PRPM soils and their parent materials is uncertain, and practitioners report a general reluctance or apprehension to invoke F21 – Red Parent Material when making wetland determinations (Jacob Berkowitz, personal communication, 2015).

Early Identification of Red Parent Material and “Terrestrial Red Beds”

As previous stated, early studies of PRPM soils suggest that these soils possess a resistance to color change due to mineralogical characteristics inherited from their parent materials. Therefore, these red soils are known to occur in association with particular geologic formations.[11] The earliest occurrences of these PRPM soils, and User Notes of the TF2 and F21 field indicators, also indicate that they are known to occur in areas characterized by dark red, sedimentary deposits (e.g. shales, sandstones, siltstones, mudstones) and/or materials derived from them (Sprecher and Mokma, 1989; Elless and Rabenhorst, 1994; Mokma and Sprecher,

[11] In geological sciences, sequences of rock are subdivided into distinct and recognizable stratigraphic units of identifiable origin and relative age range based on the petrographic, lithologic, or paleontologic features that characterize it. These units are particularly important in stratigraphy (the branch of geology concerned with the order and position of strata in relation to the geological time scale) and the general mapping of geology in an area. Going from smallest to largest in scale, the main units recognized are: bed, member, formation, group, and supergroup. A member is a name of lithologically distinct part of a formation. A formation is the primary subdivision used to distinguish a sequence (or sequences) of rock from other units, often varying in scale and boundary sharpness between other formations. A group is a set of two or more formations that share certain lithologic characteristics; and a supergroup is a set of two or more associated groups and/or formations that share certain lithological characteristics. Formations must have sufficient extent to be useful for mapping and can appear in multiple groups and/or supergroups across different geographic areas. In this document, the term “formation” is used in a more general sense and can refer to distinctive volume(s) or sequence(s) of rock that may or may not be classified at other levels as a bed, member, etc. in their areas of occurrence.

1994; Elless et al., 1996; Rabenhorst and Parikh, 2000; Ford, 2014; etc.). Additionally, the dominant iron oxide pigment within these PRPM soils has been suggested, and found, to be hematite (Elless and Rabenhorst, 1994; Mokma and Sprecher, 1994). From these observations, it is likely that these PRPM soils occur in association with red-colored, sedimentary geologic materials rich in the mineral hematite, known as "terrestrial red beds," and in transported materials (alluvium, colluvium, and glacial) derived from them.

"Red beds" are defined as detrital sedimentary rocks with reddish-brown ferric oxide pigment on grains, in pores, and dispersed in the matrix (Van Houten, 1973). Their presence in the stratigraphic record became abundant in the Precambrian eon (~1800-2000 Mya) after free oxygen began to accumulate in the Earth's atmosphere following the evolution of photosynthesizing cyanobacteria (Turner, 1980). Major constituents of red beds range across many different rock types (low- and high-grade metamorphic rocks, feldspars and oxides from igneous rocks, etc.); however, the main characteristic shared amongst all is a predominant red pigment. The two basic shades of red observed are a deeper cherry red (typical for Triassic and Paleozoic rocks) and a more orange red (generally more characteristic of rocks from the Permian period), ranging from 2.5YR to 5YR hues (Torrent and Schwertmann, 1987; Krynine, 1949). Some red pigments also have a more purplish shade and are commonly mixed with green minerals, such as chlorite and glauconite, with hues ranging from 5R to 2.5R (Torrent and Schwertmann, 1987; Krynine, 1949). Variegated sequences or alternating layers of red and sometimes drab (green-, gray-, and/or yellow-colored) materials is also common, however, at least 60% of the total formation has to be red in color in order to be classified as a red bed (MüCke, 1994; Van Houten, 1973).

The cause and origin of the red color of these deposits has also been a topic of controversy. Like PRPM soils, mineralogical analyses reveal that the red pigmentation is derived from the presence of iron oxides, predominantly the strongly pigmenting mineral hematite (MüCke, 1994; Blodgett et al., 1993; Van Houten, 1973). Although the amount of iron oxides present in these rocks has been considered a contributing factor, the average total iron content of red beds of most types ranges between 1.7 and 4.7% (Van Houten, 1973). Total iron and red pigmentation has also been shown to increase with decreasing grain size of rocks (from sandstone to mudstone types), where most of the iron is associated with the clay fraction (Van Houten, 1973).

Despite the common red pigment amongst all the red beds, geologists have also attempted to classify and distinguish between many different types of red bed deposits. Historical classifications have been made almost entirely on color variations, while others have classified red beds based on their sedimentary structures, textures, or fossil contents (Turner, 1980). For example, Clark (1962) separated red beds into the following groups: shale pebble reds, red clay conglomerates, variegated reds, cinnamon red shales, brick red, pastel red, and spattered red; encompassing color variations and texture differences observed between many different deposits considered to be red beds. However, these systems quickly became confusing as geologists discovered that red beds can come from many different tectonic and/or sedimentary associations and may form from a variety of different processes.

In regard to the formation processes of red beds (i.e. processes that contribute to the hematite-reddening of the deposits), geologists have hotly debated plausible answers to three main questions: 1) what is/are the sources of the hematite pigment; 2) are the formations syn- or post-depositional and; 3) what are the roles of sedimentation and climate in red bed reddening and formation, if any (MüCke, 1994; Van Houten, 1973; Walker, 1967; Walker, 1974)? To date, four working models have been proposed. The first, and most historically accepted, is that red beds originate in desert, oxygenated environments where intense heat results in the dehydration of ferric hydroxides in rocks to form hematite. The second, hematite or its precursor ferric hydroxide, is believed to have a lateritic-soil origin in a wet, tropical area, where it is then transported to desert basins or is incorporated into other sediments through erosion. Third, the hematite in sedimentary deposits comes from intrastratal alteration of iron-bearing grains during diagenesis[12] of rocks. And lastly, hematite originates from ferric hydroxides, however, it is of post-diagenetic age, replacing pre-existing cement of sandstones (MüCke, 1994; Turner, 1980; Van Houten, 1973; Walker, 1967; Walker, 1974).

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[12] "Diagenesis" is a broad term used to describe the processes by which sediments or sedimentary rocks change into different sedimentary rocks, encompassing all means by which chemical, physical, and mineralogical characteristics of sediments or sedimentary rocks are altered (Chilingarian and Wolf, 1988; Blodgett et al., 1993; Larsen and Chilingar, 1983). Many changes to the definition have been made since coined in 1888, and thus investigators consider a variety of processes to be considered diagenetic. To name a few, diagenesis encompasses processes of lithification at temperatures and pressures less than that required for the formation of metamorphic rocks, changes that occur to sediments following burial from the atmosphere, as well as processes of pedogenic and/or surface weathering (Chilingarian and Wolf, 1988; Blodgett et al., 1993; Larsen and Chilingar, 1983). To date, there is a lack of consensus on the definition of diagenesis and the types of processes that are considered diagenetic. For the purpose of this paper, diagenesis refers to red bed formation in the context of lithification processes and conditions less than those required for metamorphism.

Since the development of these theories, red bed classification has moved to place emphasis on differences in source areas of sediments and/or the proposed processes of red bed formation (Turner, 1980). Today, the main opinion is that post-depositional, diagenetic processes are the primary contributors to red bed formation (Blodgett et al., 1993) and that the exact origin largely depends on the basin type and depositional environment[13] in which the sediments form (MüCke, 1994). In the United States, several red bed deposits, apart from those known to derive PRPM soils listed in the TF2 and F21 field indicators, are known to occur throughout the country. Such locations include, but are not limited to: the Aspen red beds of CO (Freeman and Bryant, 1977), the “Red Racetrack” of the Black Hills in WY and SD (Robinson et al., 1964), and the Permian basins of TX, OK, and NM (Jones and Hentz, 1988; Darton, 1928; Gould and Wilson, 1927). Each of these red bed formations may be potential source rocks that produce PRPM soils applicable for use of the F21 field indicator outside of the LRRs and MLRAs currently approved for F21 indicator use.

Mineralogical Characteristics of Hematite and Hematite in the Soil Environment

In addition to the early studies that have identified sedimentary, hematite-rich deposits as potential source rocks to produce PRPM soils, several studies have further linked the cause of their resistance to redox-induced color change specifically to the presence of the mineral hematite. As previously stated, Mokma and Sprecher (1994) suggested that the weak expression of redox features in problematic soils derived from red glacial deposits surrounding the Great Lakes may be from the presence of hematite in the soils. Elless and Rabenhorst (1994) also determined that hematite was

[13] A depositional environment is a specific type of place or setting in which sediments are deposited. The environment can describe or include a combination of physical, chemical, and biological components and processes associated with the deposition of a particular type of sediment.

the only iron oxide pigment to occur in PRPM soils in the Triassic Culpeper Basin and further suggested that Al for Fe substitution in the hematite structure could be the mechanism by which the soils resist redox-induced color changes. For these reasons, a brief discussion of the characteristics of hematite and its occurrence and stability in the soil environment is presented.

Hematite (α-Fe_2O_3) is one of the five most common iron oxides to occur in soils (others are goethite, hematite, lepidocrocite, maghemite, and ferrihydrite) (Schwertmann, 1993). Pure end members of the mineral are composed of dense (hexagonal closest packed) arrangements of Fe^{3+} in octahedral coordination with oxygens. The unit cell of the mineral contains an empty octahedra, with all other octahedra being occupied by Fe^{3+} that share edges with their neighbors. In purest forms, these successive units of octahedra stack parallel to the (001) axis, sharing a common layer of oxygen anions (as faces) (Figure 2.5).

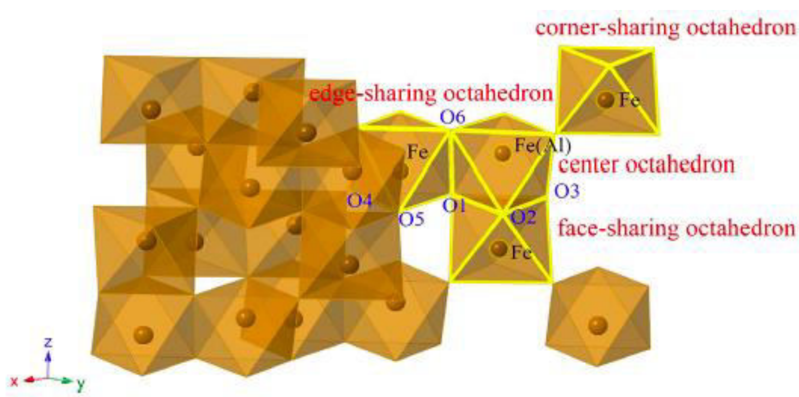

Figure 2.5. *Schematic of Fe^{3+} coordination in hematite. Figure 3 from Li et al. (2016).*

This arrangement of ions produces a crystal with a rhombohedral-shaped lattice of the hexagonal (trigonal) crystal system.[14]

[14] This coordination/arrangement of ions is a shared characteristic of many oxide minerals such as corundum (Al_2O_3), ilmenite ($FeTiO_3$), etc.

Furthermore, previous studies have shown that various metal cations (e.g. Al^{3+}, Ni^{2+}, Cu^{2+}, Zn^{2+}, etc.) can be substituted for Fe^{3+} into the hematite lattice, however, Al substitution is the most common (Schwertmann and Taylor, 1989).[15] In synthetic and naturally occurring hematites, this degree of Al substitution has been found to impact many physiochemical properties of the mineral (e.g. cell parameters, crystal size, morphology, etc.), as well as the dissolution rate of the mineral. For example, Barron and Torrent (1984) found that increased Al substitution can produce hematite crystals that are brighter (higher value) in color. Li et al. (2016) observed that increased Al substitution (~7-9 mol %) can restrict the growth of hematite crystals along the (001) axis to produce "plate-like" crystals, instead of rhombohedral-shaped crystals. Dissolution rates of goethites and hematites have also been found to be inversely related to the degree of Al substitution in the minerals (Schwertmann, 1991; Torrent et al., 1987; Cornell and Schwertmann, 2003), and has been invoked to explain why certain Oxisols were less susceptible to redox-induced dissolution in wet conditions (Macedo and Bryant, 1989). The maximum degree of Al substitution tolerated in the hematite structure is ~16 mol % (Schwertmann et al., 1979; Stanjek and Schwertmann, 1992). This Al substitution can be detected using X-Ray Diffraction (XRD) by determining the displacement of XRD [hkl] peaks characteristic of the mineral (Schwertmann, 1977) (Figure 2.6).

[15] When Al^{3+} is substituted for Fe^{3+} in the hematite lattice, the smaller ionic radius of Al^{3+} to Fe^{3+} causes a linear shrinkage in the unit cell size of hematite within increasing degrees of substitution. This shrinkage induces strain on the mineral by shortening the bonds between Al^{3+} and oxygen and subsequently lengthening the surrounding bonds where Fe^{3+} is bonded to oxygen in the octahedra.

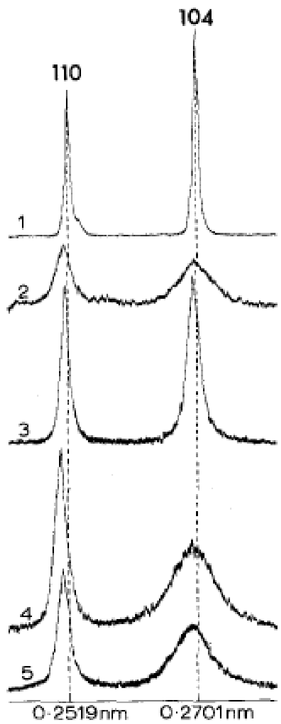

Figure 2.6. *X-ray diffractograms of hematite synthesized in aqueous suspensions containing increasing amounts of Al (1 = natural mineral reference; 2 = soil [Oxisol] hematite mineral reference; 3 = synthetic hematite from ageing ferrihydrite with 5 mol% Al substitution; 4 = synthetic hematite from ageing ferrihydrite with 15 mol % Al substitution; 5 = synthetic hematite formed from heating 5 mol % Al goethite at 320°C). Shifts from the mineral's characteristic [hkl] peaks, and lower and broader spacings of peaks, indicate increasing Al for Fe substitution within the crystal's structure. Figure 1 from Schwertmann (1977).*

The degree of displacement of the (110) [hkl] peak reflects the size of the hematite unit cell along the a_o-dimension [e.g. (100) axis] and can be used estimate the % mol Al substitution using the relationship published by Schwertmann et al. (1979) (Figure 2.7).

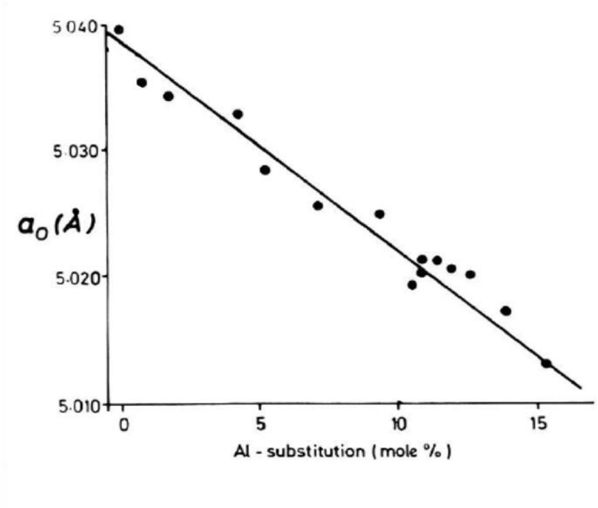

Figure 2.7. *Al substitution and the a_o parameter of synthetic hematites. Modified from Figure 2, Schwertmann et al. (1979).*

Previous research on the crystal size of hematite and its relationships to the mineral's occurrence, color, and solubility have been also investigated. For example, larger crystals of hematite have been observed in the pore spaces of dark, purplish-colored layers of red bed deposits (Mader, 1982; Heim, 1970). In work with synthetic minerals, larger crystals of hematite are known to produce materials that are darker, purplish in color compared to smaller crystals of hematite that produce soils that are brighter red in color (Schwertmann, 1993). While all iron oxides have low solubility in the soil environment (for hematite, the solubility product [expressed as pFe^{3+} + 3pOH] ranges between 42.2-43.3) (Schwertmann and Taylor, 1989; Langmuir and Whittemore, 1971), it is also understood that the solubility of iron oxides further decreases with increasing grain sizes of the minerals (Schwertmann, 2008; Langmuir and Whittemore, 1971). Furthermore, larger crystals of iron oxide minerals have been observed to have lower surface area-to-volume ratios that could slow the rate of their reduction relative to smaller crystals (Weidler, 1995). In red bed deposits, hematite crystals have been found to exist in a variety sizes from coarse specular hematite (2 -

40 µm) to ultrafine, red-colored crystals (crystals not evident when magnified 50,000 times) (Walker et al., 1981). In soils, iron oxides (including hematite) tend to occur as minute crystals (ranging between 5 and 100 nm in size) as coatings on clays and other soil mineral grains (Schwertmann, 2008; Schwertmann, 1993). This mean crystallite size of the mineral can be detected in rock and soil samples using XRD by calculating the peak broadening (e.g. "Full Width at Half Maximum" [FWHM]) of XRD [hkl] peaks characteristic of the mineral and applying the Scherrer equation[16] (Klug and Alexander, 1974).

Assessment of the Literature Review and Statement of Research Objectives

This review has provided information regarding the occurrence and understanding of problematic hydric soils derived from RPM for the identification and delineation of wetlands at the federal level in the United States. As this review has demonstrated, researchers and field scientists have observed that cases of PRPM soils have complicated wetland determinations in many areas throughout the country. Previous (TF2) and current (F21) hydric soil Field Indicators attempt to aid in PRPM hydric soil identification for wetland delineation purposes, however, several obstacles to indicator application have discouraged the use of the F21 indicator by field practitioners. Among these obstacles include: 1) minimal expression of redox features typical of many (well drained) red soils; 2) no glossary of geologic materials known to derive PRPM soils, and 3) a lack in CCPI analyses required to confirm red soils

[16] The Scherrer equation is derived from Bragg's Law and relates the mean size of minerals in a solid to the broadening of a peak in a diffraction pattern. In the equation, the mean crystallite size (nm) of a mineral in a sample is equal to the product of Bragg's Law's shape factor and the X-ray wavelength of the diffractometer, divided by the product of the cosine of the Bragg angle characteristic of the mineral and the line broadening at half the maximum intensity (FWHM) at the same Bragg angle, in radians. Instrumental line broadening of the X-Ray diffractometer must first be subtracted from the line broadening at FWHM to calculate the mean crystallite size of a mineral using the Scherrer equation (Klug and Alexander, 1974).

and their parent materials as problematic for indicator application. Thus, there is currently no comprehensive understanding of the distribution of PRPM soils and their parent materials across the U.S. for which field indicator F21 is applicable. Furthermore, the relative weak expression of hydromorphological features in PRPM soils has been linked to mineralogical characteristics of iron oxides inherited from their parent materials. However, no conclusive evidence has been presented to document the exact mechanism by which PRPM soils resist redox-induced color changes, nor have comparisons been made between these characteristics in PRPM soils and non-problematic RPM soils.

Based on these observations, the following research questions may be asked: 1) where do PRPM soils occur and what kinds of parent materials produce these soils throughout the nation, 2) what are the (resource) areas in which the F21 – Red Parent Material hydric soil field indicator can be applied, and 3) what is the exact cause of PRPM soils responsible for their resistance to the development of redoximorphic features (e.g. iron depletions) typical of most hydric soils? From these research questions, the overall objectives of this research are to: 1) determine which groups of soils and parent materials qualify as problematic RPM (using CCPI analyses) throughout the country, 2) create geospatial datasets and guidance maps for the occurrence and distribution of problematic RPM to aid in the application of field indicator F21 – Red Parent Material, and 3) better understand the fundamental cause for why PRPM soils are resistant to forming redox features typical of most hydric (wetland) conditions. The following two chapters of this document will examine each of these research questions and objectives.

Chapter 3: The Distribution of Problematic Red Parent Material Hydric Soils - the National and Regional Application of Hydric Soil Field Indicator F21 – Red Parent Material

Introduction

The United States Army Corps of Engineers (USACE) recognizes hydric soils as one of three environmental parameters (i.e. wetland hydrology, hydrophytic vegetation) for wetland identification and delineation under jurisdiction of the Clean Water Act in the United States (Environmental Laboratory, 1987). Some red soils, derived from certain red-colored parent materials, however, are problematic for hydric soil (and therefore wetland) determinations as they have weak expression of redoximorphic features (e.g. Field Indicators) typically used to identify most hydric soils in the field (referred to as PRPM soils herein). The first occurrences of these soils were mainly observed in soils derived from dark red, Triassic-aged deposits in the Mid-Atlantic (Niroomand and Tedrow, 1990; Elless and Rabenhorst, 1994; Elless et al., 1996), and have since been found to occur in many other areas distributed across the country (Mokma and Sprecher, 1994; Rabenhorst and Parikh, 2000; Ford, 2014). Early investigation of these soils suggests that they resist redox-induced color changes (and therefore have weak expression of redoximorphic features) due to mineralogical characteristics inherited from their parent materials (Mokma and

Sprecher, 1994; Elless and Rabenhorst, 1994), and therefore occur in association with particular geologic formations.[17]

To address this issue in hydric soil (and therefore wetland) determinations, the National Technical Committee for Hydric Soils (NTCHS) developed a special field indicator, TF2, later revised into a new indicator, F21 – Red Parent Material, to aid in wetland delineations affected by problematic RPM. Currently, the F21 – Red Parent Material field indicator is approved for official use in Major Land Resource Areas (MLRAs) and Land Resource Regions (LRRs) in the Mid-Atlantic (i.e. MLRA 127 of LRR N, MLRA 145 of LRR R, MLRAs 147 and 148 of LRR S), as well as for testing in all soils derived from red parent materials across the country (USDA-NRCS, 2017a). Use of the F21 indicator is restricted to soils with the expression of 7.5YR or redder (matrix) colors, 10% redoximorphic features as iron concentrations and/or depletions (in combination), and for the soil to be derived from problematic RPM. Research conducted since the creation of the original TF2 "test" indicator further resulted in the development of a laboratory procedure that can be used to identify

[17] In geological sciences, sequences of rock are subdivided into distinct and recognizable stratigraphic units of identifiable origin and relative age range based on the petrographic, lithologic, or paleontologic features that characterize it. These units are particularly important in stratigraphy (the branch of geology concerned with the order and position of strata in relation to the geological time scale) and the general mapping of geology in an area. Going from smallest to largest in scale, the main units recognized are: bed, member, formation, group, and supergroup. A member is a name of lithologically distinct part of a formation. A formation is the primary subdivision used to distinguish a sequence (or sequences) of rock from other units, often varying in scale and boundary sharpness between other formations. A group is a set of two or more formations that share certain lithologic characteristics; and a supergroup is a set of two or more associated groups and/or formations that share certain lithological characteristics. Formations must have sufficient extent to be useful for mapping and can appear in multiple groups and/or supergroups across different geographic areas. In this chapter, the term "formation" is used in a more general sense and can refer to distinctive volume(s) or sequence(s) of rock that may or may not be classified at other levels as a bed, member, etc. in their areas of occurrence.

PRPM soils, called the Color Change Propensity Index (CCPI)[18] (Rabenhorst and Parikh, 2000). User notes of the F21 indicator adopted this procedure into the definition of RPM and require that suspected soils also be "evaluated as 'problematic' with Color Change Propensity Index (CCPI) values less than 30" (USDA-NRCS, 2017a).[19]

Despite these developments, however, not all red soils derived from red-colored parent materials are "problematic" (e.g. resist redox-induced color changes) (Rabenhorst and Parikh, 2000), and thus many (well drained) red soils can still be erroneously identified as hydric during wetland determinations. The current F21 indicator also lacks comprehensive guidance, or a glossary, of RPM (as geologic formations) known to produce PRPM soils throughout the country. Recent development of the CCPI to distinguish PRPM soils from other red soils has also required soils to be evaluated as problematic "with CCPI values less than 30," however, CCPI analyses in many soils suspected to be derived from problematic RPM are lacking. For these reasons, the exact occurrence and distribution of

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[18] The Color Change Propensity Index (CCPI) is a laboratory analysis developed by Rabenhorst and Parikh, (2000) that measures the changes in [Munsell] soil color of soils following incubations with sodium dithionite (a highly reducing chemical reagent capable of reducing iron oxides in soils) over various time periods and temperatures. Soil color is read on samples with a digital colorimeter immediately following completion of incubations. Based on changes in components of the soils' colors over time for the different incubations, a numerical relationship, called the CCPI is then used distinguish between which soils are inherently resistant to changing colors (i.e. developing high-value, low-chroma, grey colors) under reducing conditions from those that are not. The equation is a composite of a hue index calculated using changes in Munsell hue and a chroma index based on changes in Munsell chroma. Munsell hue (officially notated as a combination of letters and numbers) is first converted to a numerical scale between 0 and 100 based on the hue measured for the soil before using the equation (Rabenhorst and Parikh, 2000).

[19] In the study, it was observed that all soils tested with CCPI values less than 30 were found to be "problematic" (i.e. resistant to redox-induced color changes), and therefore should qualify as problematic RPM for use with the current F21 – Red Parent Material field indicator (Rabenhorst and Parikh, 2000; USDA-NRCS, 2017a). Soils used in this study were predominantly collected from the Piedmont, Valley and Ridge, and Coastal Plain Physiographic Provinces (Rabenhorst and Parikh, 2000).

problematic RPM, and appropriate areas for application of the F21 – Red Parent Material indicator, is uncertain. The overall objective(s) of this chapter are therefore to:

1) determine the nationwide occurrence and distribution of problematic RPM by evaluating soils suspected to be associated with problematic RPM using CCPI analyses; and

2) correlate CCPI results with soil and geologic map units using available soils and geological spatial datasets (USDA-NRCS Soil Survey, U.S. Geological Survey, etc.) to generate regional and national guidance maps for appropriate application of the F21 – Red Parent Material field indicator.

The following pages of this chapter describe the strategies, methods, and materials used to accomplish these objectives, as well as the generated national and regional guidance maps for appropriate F21 – Red Parent Material application. Identified (resource) areas (as USACE Regional Supplement Regions, USDA-NRCS LRRs and MLRAs), and supplemental soils and geological information used to create and accompany the maps, is also included. Results presented in this chapter will ultimately improve the accuracy and technical defensibility of hydric soil (and therefore wetland) delineations affected by problematic RPM across the country.[20]

[20] The following sections of this chapter (i.e. methods, guidance maps, supplemental information, etc.) are also to be published by the USACE Engineer Research and Development Center, Environmental Laboratory in a Technical Report designed for use in conjunction with procedures outlined in the USACE Wetland Delineation Manual (Environmental Laboratory, 1987) and associated Regional Supplements (Berkowitz, 2011; 2012).

Materials and Methods

General Strategy

A national effort was coordinated between soil and wetland scientists from federal agencies (USACE, USDA-NRCS), state/local agencies (MAHSC, etc.), Universities, the private sector, and the Pedology Research Laboratory at University of Maryland (UMD). Letters of invitation were sent (via email in late winter/early spring of 2015) to all USDA-NRCS MLRA regional offices and USACE Districts to solicit participation among scientists and/or field personnel familiar with the RPM phenomenon to participate in the project. Letter(s) explained the goals, objectives, and expectations for the project, as well as some project logistics (soil sampling, submission of samples, CCPI analyses, etc.).[21] A cooperative arrangement was also established with the Kellogg Soil Survey Laboratory (KSSL) in Lincoln, NE in the summer of 2015 which permitted access to soil samples and/or laboratory data of suspected RPM archived at the facility. The project was also promoted at several national and regional conferences throughout the country, such as: the Bi-annual National Cooperative Soil Survey Conference (NCSS) in Duluth, MN (2015), the International Soil Science Society of America Conferences in Minneapolis, MN (2015) and Phoenix, AZ (2016), the Northeast NCSS Regional Meeting in Lake Placid, NY (2016), the Northwest NCSS Regional Meeting in Fairbanks, AK (2016), and all regional meetings held by the MAHSC from 2015 to 2017. To encourage participation in the project, CCPI data obtained for samples used in the project were shared with participants as data became available. Submission of samples for the

[21] Copies of original project letters sent to USDA-NRCS and USACE offices are provided in Appendix A of this document.

project remained open on a rolling-basis from the initial announcement of the project in early 2015 through the end of the summer in 2016 (a period of about 18 months).

Site Selection

Participating scientists were provided with information on site selection, sampling, and shipping protocols for the project. The goal was to utilize the local knowledge of field professionals and to obtain as broad a representation of soils as possible by allowing participants to select sampling sites in their areas. General guidance was given to ensure that sampled soils were particularly representative of geologic formations and/or parent material(s) potentially associated with problematic RPM. As a result, CCPI data from analyses of soils could be correlated with geological data in the mapping phases of the project. We encouraged sampling of sites with red soils suspected to be derived from and/or influenced by problematic RPM, regardless of whether or not the soils met the F21 – Red Parent Material field indicator and regardless of whether or not the soils were found within wetlands (i.e. sampling was permitted in both well and poorly drained soils as long as the soil was believed be problematic RPM). This approach was taken primarily to: 1) capture all possible inclusions of hydric soils that can occur in soil map units and delineations dominated by well drained soils as defined in USDA-NRCS Soil Survey databases;[22] and 2) to map the entire extent of where problematic RPM potentially occurs based on both soils and geological data. Some project participants suggested soils that had been previously sampled and archived at the KSSL laboratory, which were requested for analyses from the KSSL directly. Based on the reports of potential RPM soils and

[22] Information on the general use and interpretation of soils information created by the USDA-NRCS for Soil Survey is available in the National Soil Survey Handbook, Title 430-VI (USDA-NRCS, 2017b), available on the USDA-NRCS website (*soils.usda.gov/technical/handbook).*

their parent materials from participating scientists, additional soils were requested for analyses from the KSSL in suspected areas if the soils were physically available at the facility and georeferenced in the NCSS Soil Characterization Database.[23]

Soil Sampling

Project participants were requested to provide a small [approximately 500 cm^3 (1-pint)] sample from each horizon of a soil profile suspected to be derived from and/or influenced by problematic RPM. Soils were instructed to be collected using a bucket auger and/or by digging a small pit. As hydric soil field indicators mostly occur towards the soil surface (USDA-NRCS, 2017a), participants were not required to perform deep excavations, however, it was suggested to sample from all horizons at each site to a depth of approximately one meter. This depth was utilized to obtain samples that reflected properties of the entirety of the soil profile and/or the soil's parent materials to the extent possible. Simple soil descriptions, containing horizon names, depths, colors, field textures, and the presence, contrast, and abundance of any redoximorphic features, were requested to accompany samples as described in Vasilas and Berkowitz (2016). Finally, site location (GPS coordinate), a "best assessment" of the soil series[24] represented by the profile sampled, and any geological

[23] Soils from the KSSL needed to be georeferenced in the National Cooperative Soil Survey (NCSS) database for the (later) mapping phases of the project. Information on the NCSS Characterization Database is available on the USDA-NRCS website *(https://ncsslabdatamart.sc.egov.usda.gov/*).

[24] A "soil series" is a term applied to the lowest category of the national soil classification system and is used as the most common reference term in map unit names in USDA-NRCS Soil Survey databases. A soil series is similar to that of the concept of a geological formation in that they both represent volumes of material distinguishable from other materials in space. However, soil series consist of soil pedons (or profiles) that are grouped together based on similarities in their pedogenesis, chemistry, and/or other characteristics and properties that perform similarly for various land use purposes. For more information on soil series definitions, concepts, and uses, see the National Soil Survey Handbook, Title 430-VI, Part 614.6 (USDA-NRCS, 2017b), available on the USDA-NRCS website (*soils.usda.gov/technical/handbook).*

context (formation name, time period, rock type, etc.) was also requested. A data sheet was provided to record and submit all information with samples via shipment to the UMD campus.[25] Soil samples were also subject to Plant Protection and Quarantine (PPQ) regulations for shipment to the UMD campus, in accordance with the USDA Animal and Plant Health Inspection Service (APHIS).[26] All samples were permitted to be shipped wet, however, it was recommended to air-dry samples before shipment to reduce shipping costs.

Laboratory Analyses

Soils received at UMD were prepared and processed for CCPI analyses as described in Rabenhorst and Parikh (2000). Soils were dried, crushed, and sieved to pass through a 2 mm (#10) sieve. Two to three horizons (one from the surface, subsurface, and deeper subsurface) from each profile was then selected for CCPI analyses using the current F21 – Red Parent Material indicator as a guide.[27] Soil colors were measured using a Konica-Minolta digital colorimeter, with Munsell hue,

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[25] Copies of sample data sheets and sampling instructions sent to USDA-NRCS and USACE field personnel are provided in Appendix A of this document.

[26] Soils subject to PPQ regulations by APHIS were sanitized with using a heat treatment of 110ºC for 16 hours prior to shipment. It was assumed that the low temperature of the heating treatment would not alter the (mineralogical) properties of soil samples to impact results from CCPI analyses. CCPI data for all samples, and those quarantined using this method by the KSSL, are indicated in Appendix B of this document. General information on the USDA-APHIS PPQ program and permitting processes is available on the USDA-NRCS website (*https://www.aphis.usda.gov/plant_health).*

[27] Surface horizons chosen for CCPI analysis were from within 25 cm of the soil surface to encompass the 25 cm requirement of the F21 – Red Parent Material field indicator. Horizons directly below the soil surface (unless deeper than 25 cm) were not chosen to avoid local influences of other materials that may not be problematic RPM. Subsurface (B) horizons were chosen based on diagnostic subsurface properties indicated by horizon names (Bt, Bw, Bk, etc.) and based on color and redox feature requirements of the F21 field indicator (at least 7.5YR hues or redder and/or the presence of iron concentrations and/or depletions). Deeper subsurface horizons were also chosen following F21 color and redox requirements; however, horizons were chosen to represent soil parent material(s) (BC, CB, and/or C horizons) and occur at/around depths of approximately one meter.

value, and chroma recorded to the 0.1 unit. As described in Rabenhorst and Parikh (2000), soil color was measured on each sample under three different conditions:

1) initially after saturation with citrate buffer solution (no sodium dithionite added) at room temperature (25° C);
2) after treatment with citrate buffer solution and sodium dithionite at room temperature (25 ° C) for 1 hour; and
3) after treatment with citrate buffer solution and sodium dithionite at 80ºC for 4 hours.

Using these color data, a CCPI value was calculated for each sample to group them into three classes based on the CCPI: problematic if the CCPI < 30, non-problematic if the CCPI > 40, and "potentially problematic" if the CCPI was between 30 and 40. The mean CCPI value for all (2 or 3) samples analyzed for a particular profile was ultimately used to group the entire profile into the various CCPI classes.

Identification of Problematic Red Parent Material

All soils series associated with each profile (either identified by the individual submitting the sample, the USDA-NRCS using Web Soil Survey, or by the KSSL) that qualified problematic with CCPI < 30 were identified for mapping. The overall approach was to link soil series confirmed as problematic RPM with other series derived from the same parent materials or geologic formation. To do this, resources such as USDA-NRCS Official Series Descriptions (OSDs), Block Diagrams, Series

Extent Maps, as well as literature and initial reports from project participants, were utilized.[28] A soil series was added to the problematic RPM list if:

1) the soil series was confirmed as problematic RPM with CCPI < 30;
2) the soil series was documented as problematic RPM in the literature;
3) the OSD of a series indicated that it was geographically associated with a series confirmed as problematic using CCPI,[29]
4) the soil series was identified on a USDA-NRCS Block Diagram as being derived from the same parent material or formation as a soil series confirmed as problematic RPM using CCPI; or
5) the soil series was deemed associated to a series confirmed as problematic RPM with CCPI < 30 through competent personal communication with experienced soil scientists familiar with their occurrence.

Following the generation of the PRPM soil series lists, series names were joined to both the USDA-NRCS Digital Gridded U.S. General Soil Map (gSTATSGO2) and

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[28] PRPM soil series were identified using the FY2015 release of USDA-NRCS Official Series Descriptions (OSDs) and Block Diagrams. All OSDs and Block Diagrams for soils series are available online. Series Extent was predominantly determined via the University of California Davis Soil Research Laboratory's Soil Series Extent Mapping Tool available on the University's Soil Resource Lab website (*https://casoilresource.lawr.ucdavis.edu/see/).*

[29] Geographically associated series also had to be described as a red soil (with 7.5YR or redder colors like the requirements of the F21 indicator), describe similar parent materials or geological context as soil series confirmed as problematic RPM with CCPI < 30, exist in the same general location as series confirmed as problematic RPM with CCPI < 30 as evident by Soil Series Extent Maps, and/or contain comments or remarks that indicated the occurrence of the RPM phenomenon (e.g. difficulty observing redoximorphic features even though the soil is seasonally saturated, etc.). A soil series was not required to meet all of the above, but most of these criteria indicated. It should also be noted that the identification of these series was subject to interpretation and data available at the time of the lists generation. Series lists were continually updated as additional information was compiled and CCPI data became available over the course of the project.

Gridded Soil Survey Geographic (gSSURGO) map units (as found in the component tables for the map unit records) using ArcGIS 10.4 software.[30]

Furthermore, parent materials and geological units associated with soil series confirmed as problematic with CCPI < 30 were identified for mapping. Like soils information, the approach was also to generate a working list of geological units (as members, formations, groups, etc.) that qualify, or were lithologically-associated with units that qualify, as problematic RPM. A geological unit was added to the list if:

1. the geological unit was the parent material of a soil series confirmed as problematic with CCPI < 30 (as indicated by project participants, KSSL, etc.);
2. the geological unit was identified as problematic RPM in previously published literature;
3. the geological unit was mentioned by name in the OSD of a soil series confirmed as problematic RPM with CCPI <30,
4. the geological unit was shown in a USDA-NRCS Block Diagram to be associated with a series confirmed as problematic RPM with CCPI < 30;

the geological unit was mapped and was substantially overlain by an RPM soil map unit in both USDA-NRCS gSTATSGO and gSSURGO databases using ArcGIS 10.4 software.[31]

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[30] Soils data in these databases are organized in "soil map units" in which soil series are defined as "components" of the map units for digital display. Each component (i.e. soil series) is defined to occupy a certain percentage of the total area of a specific soil map unit that may or may not be divided into one or several delineations. See user information on the U.S. General Soil Map (STATSGO2) and Soil Survey Geographic (SSURGO) Database, the National Soil Survey Handbook (USDA-NRCS, 2017b), "How to Use a Soil Survey," and "What are Soil Map Units and Web Soil Survey" (Brewer, 2011), available on the USDA-NRCS website (*https://www.nrcs.usda.gov/wps/portal/nrcs/main/soils/survey/geo/*). FY2015 versions of the USDA-NRCS gSTATSGO2 and gSSURGO databases were used in mapping problematic RPM in this project.

Generation of F21 – Red Parent Material Guidance Maps

Following the end of sample submission and identification of problematic RPM (soils and parent materials), a national draft guidance map for appropriate F21 – Red Parent Material application was created. To do this, the final list of RPM soil series was joined to soil map units in the more general USDA-NRCS Digital Gridded General Soil Map (gSTATSGO2) Database (as found in the component table for the map unit records).[32] Soils map units were identified as problematic RPM if the map unit was composed of five percent or more of the soil series named on the RPM series list.[33] Likewise, geological map units in their corresponding datasets were identified as problematic RPM. Together, the RPM guidance maps represent the composite of

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[31] Prior to the collection of any RPM information, U.S. state bedrock datasets were collected from the United States Geological Survey's (USGS) website (specifically created from the Mineral Resource Program's, National Surveys and Analysis [NSA] Project), and merged together in ArcGIS 10.4 software to create a bedrock "reference map" for mapping. These datasets were ultimately used for this project (in opposition to broad-scale, conterminous U.S. datasets [1:2,500,000 to 1:5,000,000]) as they contained relevant geological nomenclature and information (i.e. formation names, rock types, ages, etc.) at regional scales (1:250,000 to 1:500,000) most useful for correlating soils and geological information for the project. Where appropriate, additional geological datasets (surficial, glacial, etc.) were also collected from the USGS website and other sources (State Geological Surveys, academic institutions, etc.) and used for mapping of RPM as well. When identifying geological map units as problematic RPM, geological map units substantially overlain by USDA-NRCS gSTATSGO and gSSURGO soil map units were corroborated as problematic RPM by referencing the geological map unit descriptions, as well as scientific literature. The geological unit was deemed problematic RPM if the unit contained substantial red-colored materials. When possible, additional soils were requested for CCPI analyses from the KSSL to corroborate the occurrence of problematic RPM in the identified area as well. All references and geological datasets used in this project are indicated in Appendix C and D of this document. For more information on the USGS Mineral Resource Program's NSA projects, see USGS Open-File Report(s) for the Preliminary Integrated Geologic Map Databases for the United States (Report Numbers: 2006-1272, 2005-1325, 2005-1324, 2005-1323, 2004-1355, 2005-1351, and 2005-1305), available on the USGS website (*https://mrdata.usgs.gov/geology/state/*).

[32] The USDA-NRCS Digital Gridded U.S. General Soil Map (gSTATSGO2) Database was ultimately used in draft and final versions of the F21 guidance maps as this dataset is a more general, broad-based inventory of soils intended for planning and management uses that cover state, regional, and national scales (1:250,000) (USDA-NRCS, 2017c; USDA-NRCS 2017b).

[33] Map units with five percent or more of PRPM soil series defined within them were ultimately identified as problematic RPM in gSTATSGO datasets as these map units often times mirrored or coincided with geological map units also identified as potential problematic RPM in relevant geological datasets used to generate RPM guidance maps.

both soils and geological information where F21 problematic RPM can potentially occur, based on CCPI analyses and pertinent parent material information (not other factors relevant to hydric soils such as drainage class, climate, etc.). In many places, the soil and geological units coincide, but in some instances, portions of the map may reflect only soils or only geological data. In a few instances, USDA-NRCS MLRAs were so dominated by RPM geology or soils map units that entire MLRAs were included as problematic RPM within the maps.[34]

From the national map, regional maps were then generated based on the locations of RPM occurrence across USDA-NRCS LRRs and MLRAs and USACE Regional Supplement Regions. Regional draft maps were then sent to USDA-NRCS MLRA offices and USACE Districts (where problematic RPM was identified) in the early winter (Jan-March) of 2017. The intent of releasing drafts of the RPM guidance maps was to solicit comment and feedback on the general accuracy of the maps from field personnel in their areas. PRPM soil series and pertinent geological information compiled to make the maps was also released for review and comment with the regional draft maps. Each region was given approximately one month to submit comments and feedback. Finally, following editing of draft maps with consideration and additional information obtained from public comment, final (national and regional) versions of guidance maps were generated for appropriate application of field indicator F21 – Red Parent Material. Supplemental soils and geological information used to generate and accompany maps was also compiled. The final RPM

[34] All datasets used for the generation of F21 guidance maps are indicated in Appendix C of this document.

guidance maps and supplementary soils and geological information are described below.

Results and Discussion

National Overview

Approximately 1,158 individual soil samples, from a total of 456 sites, were collected and analyzed for CCPI from around the country. The majority of soils were collected directly from KSSL archives (327 sites - 72%), followed by samples submitted from USDA-NRCS soil scientists (81 sites - 18%), field personnel from the USACE (21 sites - 5%), University staff and affiliates (14 sites - 3%), private sector/consulting soil and wetland scientists (10 sites - 2%), and state and/or local agencies (3 sites - 1%). From these samples, ~745 soil series from 270 recognized formations were identified as problematic RPM, all occurring within the contiguous United States.[35] Amongst all occurrences, PRPM soils were found to be associated with parent materials derived from sedimentary, hematite-rich, "terrestrial red bed"[36] formations, and transported (glacial, alluvial, and colluvial) materials derived from them. Based on the occurrence of problematic RPM across various USACE Regional Supplement Regions and USDA-NRCS resource areas, four major regions where F21 – Red Parent Material may appropriately be applied have been identified:

1. Northeast and Mid-Atlantic

[35] A handful of soil samples (4) from two sites were collected and analyzed for CCPI from the state of Hawaii, however, none were found to qualify as problematic RPM with CCPI < 30. No samples were submitted for CCPI from Alaska, Puerto Rico, or any other United States territories during the duration of this project.

[36] "Red beds" are defined as detrital, siliciclastic sedimentary rocks or sequences (conglomerates, sandstones, siltstones, shales) where at least 60% of the total stratum is pigmented red from the presence of ferric oxides, predominantly the iron oxide mineral, hematite. For more information on the characteristics, origins, or classification of "red beds," see Krynine (1949); Van Houten (1973); Turner (1980) and Bigham et al. (1993), amongst others.

2. Great Lakes

3. South-Central

4. Desert Southwest and Western Mountains (Figure 3.1).

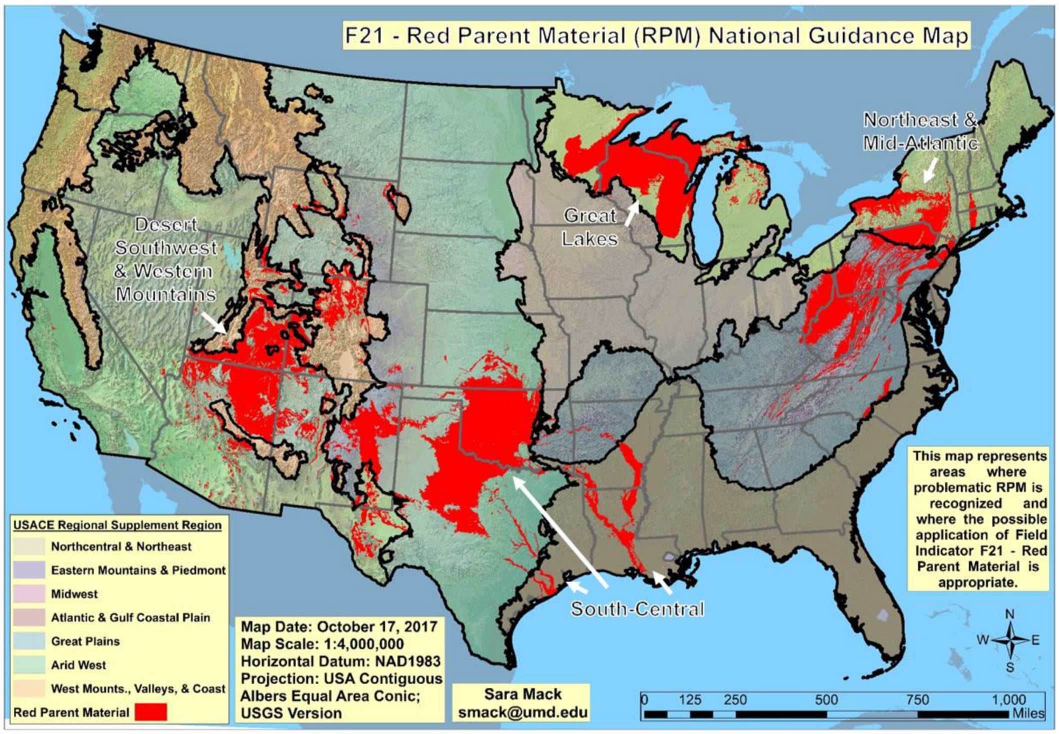

Figure 3.1. *National guidance map for appropriate application of the F21 - Red Parent Material (RPM) field indicator in the United States. Red areas indicate locations with soils and geological formations where problematic RPM are possible. From these areas, four major RPM regions across the various USACE Regional Supplement Regions have been identified (from right to left): the (1) Northeast and Mid-Atlantic, (2) Great Lakes, (3) South-Central, and (4) Desert Southwest and Western Mountains. Groups of soils and parent materials within each of these RPM regions are further highlighted and discussed in regional guidance maps in the remaining sections of this chapter. Note that suspected RPM soils in these areas must also meet current color requirements of the F21 field indicator for application. To date, problematic RPM has only been identified in the conterminous United States (no RPM has been identified in AK, HI, Puerto Rico, etc.).*

The following sections describe each of these four major regions regarding: sample acquisition, resource areas (as USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs) where F21 – Red Parent Material may appropriately be applied, and relevant soils and geological information on the problematic RPM in the areas to guide potential F21 – Red Parent Material indicator use.

Northeast and Mid-Atlantic Region

A total of 319 soil samples from 129 sites (~28% of the total 456 sites) were submitted and analyzed for CCPI from the Northeast and Mid-Atlantic region. Of these, 181 samples (68 sites) were provided from KSSL archives, 91 samples (29 sites) from USDA-NRCS soil scientists, 24 samples (11 sites) by University affiliates, 21 samples (9 sites) from private sector soil and wetland scientists, and 6 samples (3 sites) from state and/or local agencies (State Department of Natural Resources, etc.). From these samples, problematic RPM has been identified for appropriate use of the F21- Red Parent Material indicator in fourteen MLRAs of five major LRRs in the Northcentral and Northeast and Eastern Mountains and Piedmont Regional Supplement Regions defined by the USACE (Table 3.1).

Table 3.1. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas within this study's Northeast and Mid-Atlantic region where application of the F21 - Red Parent Material field indicator is appropriate.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	L – Lake States Fruit, Truck Stop, and Dairy Region	101 – Ontario-Erie and Finger Lakes
	R – Northeastern Forage and Forest Region	140 – Glaciated Allegheny Plateau 142 – St. Lawrence-Champlain Plain 144A – New England and Eastern New York Upland 145 – Connecticut Valley
Eastern Mountains and Piedmont	N – East and Central Farming and Forest Region	124 – Western Allegheny Plateau 125 – Cumberland Plateau 126 – Central Allegheny Plateau 127 – Eastern Appalachian Ridges and Valleys 128 – Southern Appalachian Ridges and Valleys 130A – Northern Blue Ridge
	P – South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	136 – Southern Piedmont
	S – Northern Atlantic Slope Diversified Farming Region	147 – Northern Appalachian Ridges and Valleys 148 – Northern Piedmont

A guidance map for the potential occurrence of problematic RPM, and therefore the appropriate application of field indicator F21 – Red Parent Material, in the Northeast and Mid-Atlantic region is shown in Figure 3.2.

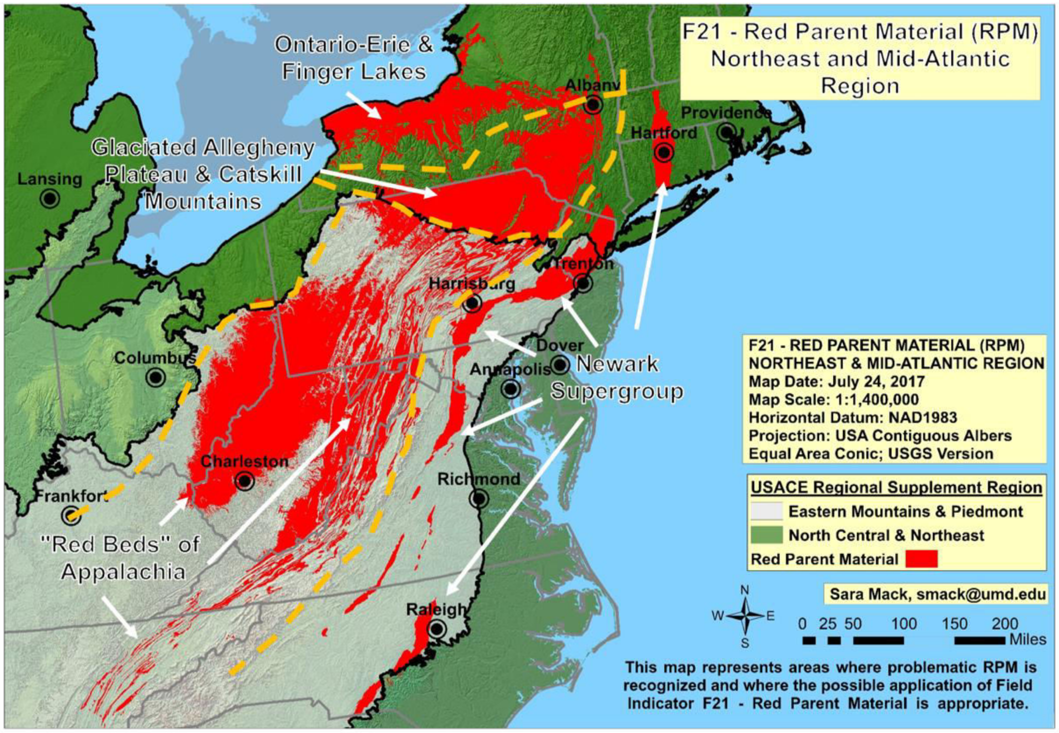

Figure 3.2. *Guidance map for appropriate application of the F21 - Red Parent Material (RPM) field indicator in the Northeast and Mid-Atlantic region. Red areas indicate locations with soils and geological formations where problematic RPM are possible. Note that suspected RPM soils in these areas must also meet current color requirements of the F21 field indicator for application.*

The overall Northeast and Mid-Atlantic region encompasses considerable topographic, climatic, and geologic diversity, with problematic RPM stretching across portions of thirteen U.S. states: Connecticut, Kentucky, Massachusetts, Maryland, New York, New Jersey, North Carolina, Ohio, Pennsylvania, South Carolina, Tennessee, Virginia, and West Virginia. Generally, problematic RPM is differentiated between northern and southern portions of the overall region by the southernmost extent of Pleistocene glaciations. The northern portions include USDA-NRCS LRRs and MLRAs within the USACE Northcentral and Northeast Regional Supplement Region (MLRA 101 in LRR L, MLRAs 140, 142, and 145 of LRR R). RPM in these areas is generally characterized as plateaus, broad valleys, and steep to gently rolling plains blanketed by a variety of glacial landforms such as till plains, drumlins, moraines, outwash deltas, eskers, kames, and lake beds (USDA-NRCS, 2006). Southern portions of this region include USDA-NRCS LRRs and MLRAs of the USACE Central Mountains and Piedmont Regional Supplement Region (MLRAs 124, 125, 126, 127, 128 and 130A of LRR N, 136 in LRR P, and 147 and 148 in LRR S). The RPM in these areas is characterized mostly by rugged, sharp to less steep ridges, the Appalachian Mountains, and narrow to broad basins or valleys formed by differential erosion of bedrock (USDA-NRCS, 2006). PRPM soils in this area are therefore predominantly bedrock controlled, or occur as transported materials as colluvial deposits down steep slopes and mountains and/or alluvial deposits associated with the region's watersheds in low-lying basins and valleys.

Within these general areas in the Northeast and Mid-Atlantic RPM region, however, four distinctive groups of soils and parent materials have been identified where the F21 – Red Parent Material indicator may be applicable:

1. Soils derived from acid, red-colored, Paleozoic-aged, sedimentary "red beds" of Appalachia;
2. Soils derived from reddish-colored glacial deposits associated with the Glaciated Allegheny Plateau and Catskill Mountains;
3. Soils derived from reddish-colored till and (glacio)lacustrine deposits of the Erie-Ontario Lowlands/Ontario-Erie Plain and Finger Lakes region; and
4. Soils derived from the reddish-colored, sedimentary rocks of the (Mesozoic) Newark Supergroup.

The following sections describe the nature of the four groups of soils and parent materials that are recognized as problematic RPM (including soil series and geological formations). These areas are also highlighted on RPM guidance maps showing where the indicator may be applied. Where appropriate, additional guidance on use and application of the F21 – Red Parent Material indicator is given as "user notes."

Paleozoic "Red Beds" of Appalachia

Problematic RPM of this group in the Northeast and Mid-Atlantic region is restricted to a collection of Paleozoic-aged, continental red beds found within the Appalachian Plateaus and Valley and Ridge physiographic provinces that make up the (Southern and Central) Appalachian Mountains and foreland basin.[37] This mountain range and foreland basin were ultimately formed by lithospheric loading that occurred during three mountain building events (known as orogenies, specifically the Taconic, Acadian, and Alleghenian respectively), between what is today known as the North American and African tectonic plates during the Paleozoic era. The formation of the mountains, and their subsequent erosion, resulted in the deposition of a variety of sedimentary rocks (shales, siltstones, sandstones, limestones, etc.) during passive continental margins between the last 500 to 300 Mya.

The continental red beds that produce PRPM soils were generally deposited during two distinct time intervals, associated with specific depositional

[37] The Appalachian Mountains and foreland basin is actually subdivided into four physiographic provinces: the Appalachian Plateaus, Valley and Ridge, Blue Ridge, and Piedmont provinces. Problematic RPM associated with the continental red beds in the Appalachian Mountains and foreland basin in this RPM region are only found in the Appalachian Plateaus and Valley and Ridge provinces.

environments,[38] in the Paleozoic era. The first of which occurred during a passive continental margin following the uplift and erosion of the Taconic mountains, sometimes referred to as the "Siluro-Devonian Interorogenic calm"[39] (Haynes et al., 2015). At this time, clastic materials (that would become the red beds) were eroded and carried westward from the Taconic Mountains by braided and meandering streams to be deposited into fluvial and marginal-marine (i.e. coastal mudflat and tidal-flat) environments along the edge of a marine-submerged foreland basin to the west (Mora and Driese, 1999) (Figure 3.3).

[38] A depositional environment is a specific type of place or setting in which sediments are deposited. The environment can describe or include a combination of physical, chemical, and biological components and processes associated with the deposition of a particular type of sediment.

[39] This interorogenic calm is a time spanning across the late-Ordovician, through the Silurian, to the early Devonian periods. During this time, the region that would become the Appalachian Mountains and foreland basin today experienced an oxidizing, arid to semi-arid tropical climate, as well an overall rise in sea level (Haynes et al., 2015).

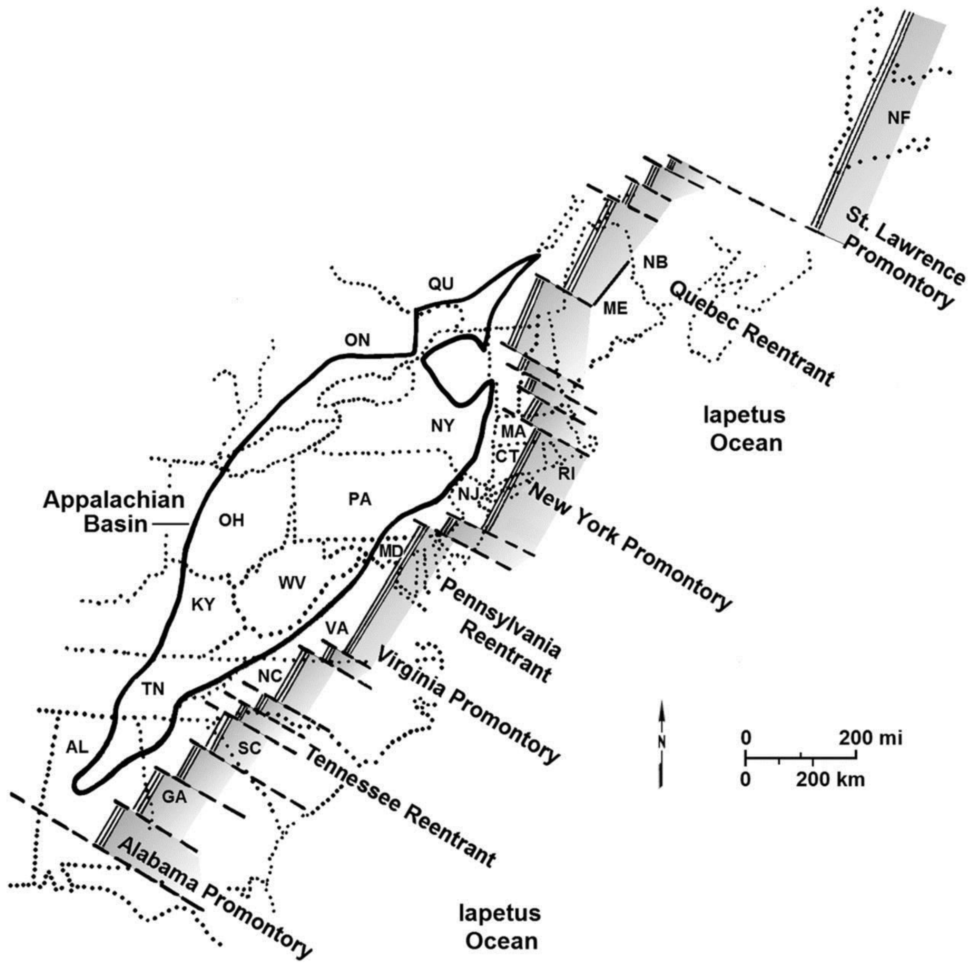

Figure 3.3. *Map of the former eastern margin of the ancient North American tectonic plate (Laurentia) in the eastern United States following the Taconic orogeny in the late-Ordovician. Map shows the possible positions of transform faults formed from the Taconic orogeny relative to promontories and re-entrants of the Precambrian-Cambrian rifted margin. The Appalachian Basin formed west of this Taconic mountain range and infilled with sediments carried from the mountains in the east. Figure 1 from Ettensohn and Lierman (2015), based on Ettensohn (2008).*

These red clastic materials would later be buried and overlain by carbonate rocks deposited from the return of a shallow sea, known as the Iapetus Ocean, as the mountains completely eroded in the late-Silurian and early-Devonian periods (Haynes et al., 2015). Formations identified as problematic red beds (or those that are known to contain them) that represent this time are the Clinton Group (Ziegler and McKerrow, 1975), Juniata (Driese and Foreman, 1992), Rose Hill (Lu et al., 1994), and McKenzie formations (Patchen and Smosna, 1975).

The second interval in which continental red beds were deposited occurred primarily during the "Mississippian Interorogenic calm"[40] (Haynes et al., 2015). During this time, the Acadian mountains that formed up until the mid-Devonian were eroding, and sediments that would become the red beds were again carried westward from the mountain range to the submerged-marine basin. These sediments were primarily carried down broad alluvial fans and deposited by large rivers systems in pro-grading deltaic environments to form a large depositional landmass called the "Catskill clastic wedge" or "Catskill Delta"[41] (Walker and Harms, 1971; Kent, 1985; Scheckler, 1986; Mora and Driese, 1999; Slingerland et al., 2009).

Within the delta and along transitional zones between the mountains and the basin, these sediments became associated with heavily vegetated coastal swamp-, marsh-, and mire-type environments typical of the area during the Pennsylvanian period (Joeckel, 1995; Greb et al., 2009). Tectonic and (glacio)eustatic changes in sea levels occurred during this time interval as well, resulting in periodic returns and retreats of the shallow Iapetus Ocean that buried and/or flooded these sediments in the coastal-margin along the edge of the basin (Cotter and Driese, 1998; Greb et al., 2009). Red bed formations (or formations that are known to contain them) that are representative of this time period include the: Mauch Chunk Formation/Mauch Chunk Group (Barrell, 1907; Brezinski, 1989), Catskill Formation (Slingerland et al., 2009), Conemaugh Group (Condit, 1909; Joeckel, 1995; Daeschler and Cressler, 2011),

[40] This calm is characterized similarly to that of the Siluro-Devonian calm that occurred prior (passive continental margins, a warm, oxidizing climate, etc.). This is a time period spanning from the mid-Devonian, through the Mississippian, and into the early-Pennsylvanian periods (Haynes et al., 2015).

[41] This area formed between the eroding Acadian mountains in the east and the marine-submerged basin to the west. Today, this is an area generally known as the "Catskills," located in south central NY, and extends southward in east-central PA through the folded Appalachians and Allegheny Plateau (Walker and Harms, 1971; Kent, 1985).

Dunkard Group (Beerbower, 1961; Arkle, 1974), Maccrady formation/shale (Mora and Driese, 1999), and Foreknobs (formerly Chemung) formations (Terry et al., 2013).

Today, these red beds are heavily interbedded and deformed, particularly from the last mountain building event known as the Alleghenian (sometimes referred to as Appalachian) orogeny, initiated in the late-Pennsylvanian (~320-300 Mya) (Haynes et al., 2015; Greb et al., 2009). All sediments deposited prior (that were adjacent to or within the basin, including the red beds), were uplifted and squeezed into great folds that ran perpendicular to the direction of the forces of the colliding landmasses.[42] During the early Mesozoic (220-200 Mya), the forces that created the Appalachian Mountains were stilled and the great supercontinent, Pangea, that formed by this landmass collision, began to rift apart (Luttrell, 1989; Haynes et al., 2015). Subsequent weathering and erosion of the Appalachian Mountains would provide sediments to form new rocks throughout the Mesozoic era to the present day, however, no sedimentary rocks remain in the Appalachian region from these times (Poag and Sevon, 1989). Today, these red beds are commonly exposed at the surface in lineated, fining-upward sequences. They routinely occur amidst a multitude of

[42] The sea level of the Iapetus Ocean also dropped, exposing sediments and rocks formed within the submerged basin. The foreland basin area itself was also uplifted rather uniformly to form the relatively flat, plateau areas towards the north of the Alleghenian Plateaus province.

other Paleozoic sedimentary rocks also elevated during the great uplift and erosion of the Appalachian Mountains during and following the Alleghenian orogeny.[43]

The distribution of problematic RPM and their associated soils derived from the Paleozoic "Red Beds" of Appalachia are shown in the RPM guidance map for the Northeast and Mid-Atlantic region (Figure 3.2). Table 3.2 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Paleozoic "Red Beds" of Appalachia.

Table 3.2. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Paleozoic "Red Beds" of Appalachia.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Eastern Mountains and Piedmont	N – East and Central Farming and Forest	124 – Western Allegheny Plateau 125 – Cumberland Plateau and Mountains 126 – Central Allegheny Plateau 127 – Eastern Appalachian Ridges and Valleys 128 – Southern Appalachian Ridges and Valleys
	S - Northern Atlantic Slope Diversified Farming Region	147 – Northern Appalachian Ridges and Valleys

Table 3.3 lists the geological formations and soil series recognized as potential problematic RPM (included in RPM guidance maps) that are associated with the Paleozoic "Red Beds" of Appalachia.

[43] It is also interpreted that the red color of the problematic red beds reflects the warm, oxygenated climate that occurred during both the Silurian-Devonian and Carboniferous (Mississippian and Pennsylvanian) periods when they were predominantly deposited. Many are also classified or referred to as (vertic) paleosols (stratum or volumes of sediments that formed as a soil in a past geological period) (Kraus, 1999), and contain a multitude of pedogenic features such as clay-skinned peds, slickensides, calcareous nodules, and/or root impressions (Gray and Nickelsen, 1989; Driese and Foreman, 1992; Driese et al., 1992; Joeckel, 1995; Mora and Driese, 1999; Catena and Hembree, 2012).

Table 3.3. Geological formations and soil series identified as potential problematic RPM that are associated with the Paleozoic "Red Beds" of the Appalachia.

Geological Formation(s)		Soil Series	
Bloomsburg Formation	Foreknobs Formation	Albrights	Meckesville
Bloomsburg Red Beds	Glenshaw Formation	Alcoa	Moshannon
Bluefield Formation	Greenbriar Formation	Allenwood	Neubert
Bluestone Formation	Greenbriar Group	Basher	Peabody
Casselman Formation	Greene Formation	Belpre	Pipestem
Catskill Formation	Hampshire Formation	Birdsboro	Raritan
Beaverdam Run Member	Hinton Formation	Calvin	Red Hills
Berry Run Member	Holston Formation	Cateache	Senecaville
Clarks Ferry Member	Huntley Mountain Formation	Coghill	Sensabaugh
Duncannon Member	Juniata Formation	Corryton	Steekee
Irish Valley Member	Maccrady Shale	Craigsville	Summitville
Long Run Member	Maccrady Formation	Gallia	Tellico
Packerton Member	Mauch Chunk Formation	Hackers	Ungers
Poplar Gap Member	Mauch Chunk Group	Hustontown	Upshur
Sawmill Run Member	McKenzie Formation	Leck Kill	Vandalia
Sherman Creek Member	Monongahela Formation	Lehew	Vandergrift
Towamensing Member	Monongahela Group	Linden	Vincent
Walcksville Member	Pennington Formation	Kedron	Watson
Chemung Formation	Pennington Group	Klinesville	Woodsfield
Clinton Group	Rose Hill Formation	Madsheep	
Conemaugh Formation	Slide Mountain Formation		
Conemaugh Group	Washington Formation		
Dunkard Group	Waynesburg Formation		

Paleozoic "Red Beds" of Appalachia: F21 – Red Parent Material User Notes

Throughout most of this region, many of the recognized PRPM soils are derived directly from their underlying Paleozoic bedrock as residuum. These soils typically contain a significant amount of coarse fragment (as channers), are silty to clayey in texture, and occur on summits, ridgetops, and backslopes in higher parts of the landscape (e.g. Belpre, Calvin, Cateache, Leck Kill, Peabody, and similar soils). Some soils are more sandy or loamy in texture from incorporation of materials weathered from formations that contain predominantly sandstone sequences (e.g. Lehew, Madsheep, Ungers and similar soils). PRPM soils can also exist as colluvial deposits derived from the underlying red beds. These soils typically occur along backslopes and/or at the footslopes of mountains, steep hills, and ridges that currently characterize the region (e.g. Hustontown, Kedron, Pipestem, Vandalia and similar soils). Because of the interbedded nature of the bedrock, it must also be noted that these residual and colluvial soils can be intermixed with materials from a variety of other sedimentary bedrock sources (gray/brown shales, coal beds, limestones, evaporites, etc. also deposited throughout the Paleozoic era) that are not necessarily problematic RPM. The PRPM soils indicated in Table 3.3 are typically mapped to occur in very close proximity to their derivative red bed formations, and therefore, awareness of the red beds is essential when making F21 wetland determinations in these areas.

Furthermore, from their geological history, the problematic red bed formations themselves tend to be interbedded and/or associated with a variety of carbonate rocks and deposits (limestones, dolomites, etc.).[44] These carbonate rocks can also produce soils that are red in color, however, they are not necessarily problematic in nature. Therefore, in addition to knowing the locality of RPM red bed formations when making F21 hydric soil determinations, an understanding of their overall association with carbonate deposits is also useful. Some PRPM soils are recognized as calcareous, or noted to be derived from calcareous red shales and siltstones, that reflect this influence of carbonate materials within the underlying red bedrock (e.g. Belpre, Upshur, and similar soils). Additional CCPI analyses are recommended to be used to confirm the presence of problematic RPM in these cases.

In addition to the residual and colluvial soils, a number of alluvial deposits derived from the Paleozoic red beds are also recognized. These soils tend to be more sandy or loamy in texture, contain more rounded coarse fragments (as gravels), and

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[44] This carbonate deposition is characteristic of the marginal-marine and deltaic environments that the red beds were deposited in during the Siluro-Devonian and Mississippian interorgenic calms. Sea level encroachment and fluctuation from the Iapetus Ocean in foreland basin likely resulted in prolonged flooding and deposition of carbonate rocks in addition to deposition of the terrestrial red bed sediments from mountain sources.

occur in drainage ways, on floodplains associated with streams and rivers in the area (e.g. Basher, Birdsboro, Craigsville, Gallia, Moshannon, Senecaville, Sensabaugh, and similar soils).

Lastly, while the region was never covered by glaciers during the Pleistocene (last 2 My), some northern areas (towards central PA in closer proximity to the Catskills), as well as some areas of higher elevation, are interpreted to be glacially deposited and/or translocated by (peri)glacial processes (e.g. Albrights, Meckesville, Leck Kill and similar soils). Some soils are also recognized as very old glacial deposits from periods of Pre-Wisconsian glaciation (e.g. Allenwood, Watson, and similar soils), also towards the Catskills. In western areas of the region (eastern OH/western WV), some RPM soils exist as silty alluvial deposits and/or clayey lacustrine sediments deposited by two large ice-dammed lakes in the present Monongahela and Teays valleys during the last Wisconsinan ice age (e.g. Vincent and similar soils). The red color and problematic nature of these glacial deposits, alluvial soils, and lake sediments is derived from the Paleozoic red bed formations commonly found in the area.

Glaciated Allegheny Plateau and Catskill Mountains

Problematic RPM of this group is restricted to glacially deposited and re-worked materials derived from “red bed” formations associated with the formation of the Catskill Delta and Catskill Mountain range, found primarily within MLRA 140 in east-central PA and southeastern NY. Similar to the red beds that occur in the more southern Appalachian system, these red sediments originated as eroded materials from the Acadian Mountains that were deposited in vegetated marginal-marine and deltaic environments at the boundary between the mountain range and submerged foreland basin during the Devonian to Mississippian periods (~ 420-350 Mya) (Walker and Harms, 1971; Kent, 1985; Ver Straeten, 2013). A warm, tropical, oxygenated environment existed at this time, and sea level fluctuations resulted in minor deposition of carbonate rocks (limestones, dolomites, etc.) that are now interbedded with the terrestrial red bed sediments (Cotter and Driese, 1998; Slingerland et al., 2009). These red beds were eventually buried, uplifted, and exposed at the surface through erosion during and following the Alleghenian orogeny much like that of red bed formations in the more southern and central Appalachian Mountain system discussed previously (Ver Straeten, 2013).

In contrast to the related red bed formations of southern Appalachia, however, these areas were covered completely by ice during multiple episodes of glaciation in the Pleistocene. The area that is the Catskill Mountains in southeastern NY today was once a flat-plateau region that has been since eroded into sharp relief from watercourses and glaciers following the end of the Alleghenian orogeny to present day (Ver Straeten, 2013).[45] PRPM soils in this group are ultimately derived from Paleozoic red bed formations of the Catskill Delta, but have been modified and/or transported throughout the area following scouring and melt out of the glaciers spanning the Pleistocene epoch (2 Mya to 12 Kya). The southern boundary of the RPM area in PA represents the southernmost extent of the Laurentide ice sheet during the last Wisconsinan glaciation.

[45] As continental drift pushed up the Appalachian Mountains during the Alleghenian orogeny, this delta region uplifted relatively uniformly into a flat plain or plateau, rather than small mountain ranges like that of more southern Appalachian systems discussed previously (see *Paleozoic "Red Beds" of Appalachia* section).

The distribution of problematic RPM and their associated soils within the Glaciated Allegheny Plateau and the Catskill Mountains area is shown in the RPM guidance map for the Northeast and Mid-Atlantic region (Figure 3.2). Table 3.4 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Glaciated Allegheny Plateau and the Catskill Mountains area.

Table 3.4. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Glaciated Allegheny Plateau and the Catskill Mountains area.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Eastern Mountains and Piedmont	R – Northeast Forest and Forage Region	140 – Glaciated Allegheny Plateau and the Catskill Mountains

Table 3.5 lists the geological formations and soil series recognized as potential problematic RPM (included in RPM guidance maps) that are associated with the Glaciated Allegheny Plateau and the Catskill Mountains area.

Table 3.5. Geological formations and soil series identified as potential problematic RPM that are associated with the Glaciated Allegheny Plateau and the Catskill Mountains area.

Geological Formation(s)	Soil Series	
Catskill Formation	Bash	Monguap
Beaverdam Run Member	Barbour	Morris
Berry Run Member	Basher	Norchip
Clarks Ferry Member	Cadosia	Norwich
Duncannon Member	Cheshire	Onteora
Irish Valley Member	Elka	Oquaga
Long Run Member	Halcott	Suny
Packerton Member	Hawksnest	Tor
Poplar Gap Member	Gretor	Trestle
Sawmill Run Member	Lackawanna	Tunkhannock
Sherman Creek Member	Lewbeach	Vly
Towamensing Member	Linden	Wellsboro
Walcksville Member	Maplecrest	Willowemoc
Slide Mountain Formation	Menlo	Wyoming

**Note –These geological formations also occur in southern and central portions of the Appalachian Mountain system discussed in the "Paleozoic Red Beds of Appalachia" section prior.*

Glaciated Allegheny Plateau & Catskill Mountains: F21- Red Parent Material User Notes

PRPM soils are possible in areas dominated by channery and loamy glacial till deposits found on till plains, hilltops, ridges, and mountainous hillsides (e.g. Elka, Lackawanna, Lewbeach, Willowemoc and similar soils). Other recognized areas are dominated by water-sorted glacial materials on outwash terraces, kames, and valley trains (e.g. Trestle, Tunkhannock, Wyoming, and similar soils). Many soils on the till plains are shallow to the bedrock, and typically occur in close proximity to the Catskill Mountain range (Slide Mountain) in eastern New York (e.g. Halcott, Hawksnest, Mongaup, Oquaga, Tor, Vly, and similar soils). Other areas are recognized as concave, upland depressions or seeps where soils have dense, root restricting layers that perch water in the subsurface, known as fragipans (e.g. Norchip, Norwich, Menlo, Onteora, Wellsboro, and similar soils). A number of sandy and gravelly alluvial deposits are also recognized on floodplains, alluvial fans, and low terraces (Bash, Barbour, Basher, Linden and similar soils). Some areas are also recognized to contain (pre-)Wisconsinan till deposits and/or colluvial deposits that transition between the glaciated regions of the Allegheny Plateau and Catskill Mountain area into the lower Appalachian system dominated predominantly by residual and colluvial deposits (e.g. Albrights, Allenwood, Leck Kill, Watson, and similar soils) (see *Paleozoic "Red Beds" of Appalachia: F21 User Notes* prior).

Ontario-Erie Plain and Finger Lakes

The Ontario-Erie Plain and Finger Lakes region, also known as the Erie-Ontario Lowlands, is characterized both by a plateau-like lacustrine plain, and a series of eleven narrow, parallel lakes oriented north-south in the north-central portion of New York state (Isachsen et al., 2000; Cadwell and Muller, 2004). This overall area is shaped by the carving and scouring of glaciers that moved southward into the state from the Hudson Bay area, marking the initiation of the last Pleistocene glaciation around 2 Mya (Isachsen et al., 2000; Cadwell and Muller, 2004). A series of northward-flowing rivers, that would later become the Finger Lakes, were gouged into deep troughs by a combination of stream erosion and episodes of glacial advance and retreat, ripping up underlying bedrock composed predominantly of Paleozoic sedimentary rocks (Engeln, 1988).

During glacial meltout from the area about 11-13 Kya, meltwaters carrying glacial debris entered and filled the deepened valleys. Steep slopes and moraines and drumlins formed from the meltout eventually blocked the path of meltwaters to the south, resulting in the formation of the flat plain of the area consisting largely of lake-laid sediments (Cadwell and Muller, 2004). As glacial retreat continued, meltwaters eventually drained to the east towards the Atlantic Ocean, exposing the lake-laid sediments of the Ontario-Erie plain and isolating the deeply trenched water bodies currently known as the Finger Lakes today (Engeln, 1988; Cadwell and Muller, 2004).

The underlying bedrock of this area consists predominantly of Ordovician-Silurian-, and Devonian-aged conglomerates, sandstones, shales, and limestones deposited as New York transitioned to a terrestrial environment from under the salty, Iapetus and Rheic Oceans (Skiba; Isachsen et al., 2000). Many of these formations, particularly those dated from the Silurian-Devonian periods, are recognized to contain sequences or layers of dark red-colored shales and hematite beds (Alling and Briggs, 1961; Brett et al., 1994; Isachsen et al., 2000).[46] Problematic RPM may occur throughout the glaciated lake plain and Finger Lakes area, predominantly as dark, red-colored tills and lake-laid sediments which inherited their red colors and problematic nature from this underlying bedrock.

The distribution of problematic RPM and their associated soils within the Ontario-Erie Plain and Finger Lakes area is shown in the RPM guidance map for the Northeast and Mid-Atlantic region (Figure 3.2). Table 3.6 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Ontario-Erie Plain and Finger Lakes area.

Table 3.6. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Ontario-Erie Plain and Finger Lakes area.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	L – Lake States Fruit, Truck Top, and Dairy Region	101 – Ontario-Erie Plain and Finger Lakes
	R – Northeast Forest and Forage Region	142 – St. Lawrence-Champlain Plain 144A – New England and Eastern New York Upland, Southern Part

Table 3.7 lists the geological formations and soil series recognized as potential problematic RPM (included in RPM guidance maps) that are associated with the Ontario-Erie Plain and Finger Lakes area.

[46] These formations are equivalent to/have been correlated with the Silurian-Devonian-aged red beds found throughout the Appalachian Mountains and foreland basin in the Appalachian Plateaus and Valley and Ridge physiographic provinces. The current Ontario-Erie Lowlands province was once a part of the Appalachian foreland basin in the early Paleozoic (Woodrow et al., 1988; Ryder et al., 2007; Ettensohn, 2008) (see Figure 3.3, *Paleozoic "Red Beds" of Appalachia* section prior).

Table 3.7. Geological formations and soil series identified as potential problematic RPM as associated with the Ontario-Erie Plain and Finger Lakes area.

Geological Formation(s)	Soil Series	
Clinton Group	Alton	Lockport
Lockport Group	Appleton	Odessa
Medina Group	Barre	Ontario
Queenston Formation/Shale	Cayuga	Ovid
Rondout Formation	Cazenovia	Romulus
Salina Group	Churchville	Schoharie
Camillus Formation	Hilton	
Syracuse Formation	Lairdsville	
Vernon Formation	Lakemont	

**Note – geological formations identified as potential problematic RPM in the Ontario-Erie Plain and Finger Lakes are typically blanketed by tills, outwash, and other types of glacial deposits in the area that may or may not be PRPM soils. Therefore, soils series presented in this table, as well as local knowledge of the surficial geology in the area, may be more useful than bedrock geological information when applying F21 during hydric soil determinations. These formations were included in RPM guidance maps for the Northeast and Mid-Atlantic region (Figure 3.2) as they are the source rocks for the PRPM soils in the area.*

Ontario-Erie Plain and Finger Lakes: F21 – Red Parent Material User Notes

Examples of PRPM soils derived from till deposits include the Appleton, Cazenovia, Hilton, Lairsdville, Lockport, Ontario, and similar soils. These soils tend to be poorly sorted with or without rock fragments, and are typically found on undulating till plains and drumlins in the area. Some PRPM soils, such as the Lockport and similar, are shallow till deposits, with underlying red shale bedrock occurring within a meter of the surface of the profile. Examples of PRPM soils found on the lacustrine plains include the Barre, Lakemont, Odessa, Ovid, Schoharie, Romulus, and similar soils. These soils are particularly dark-red in color, clayey textured, and possess a stratified, “varved” pattern in deposition that is characteristic of lacustrine deposits (especially in their lower horizons). Many of these problematic tills and lacustrine soils are also calcareous, sometimes containing the presence of secondary carbonates.

Newark Supergroup

The Newark Supergroup is recognized as a collection of exposed, lithologically- and structurally-related continental sedimentary rock sequences characterized as fluvial red beds and lacustrine deposits deposited during the early-Mesozoic era approximately 220 Mya (Smoot, 1991). Occurrence of these materials is restricted to a trough of rift valleys or basins formed in the early phases of continental rifting that took place as (what are the current) North American and African tectonic plates separated during the initial breakup of supercontinent Pangea in the late Triassic period (Luttrell, 1989). The exposed basins run parallel to the Appalachian mountains from Nova Scotia to South Carolina, and are bounded by both Precambrian-to-early-Paleozoic faults and Cretaceous sedimentary rocks (Schlische, 1992). The group is separated into structural zones differentiated by faulting, cyclic patterns in sediment deposition, and the overall thickness of sediments that infilled from surrounding continental sources over a period of approximately forty-five million years since basin formation (Schlische, 1992). Today, there are roughly twenty to thirty recognized basins of the Supergroup, each containing separate series and/or sequences of rocks as members, formations and/or groups (Olsen, 1978; Luttrell, 1989; Smoot, 1991; Olsen et al., 1991). Figure 3.4 shows the recognized basins that are exposed at the surface in the United States.

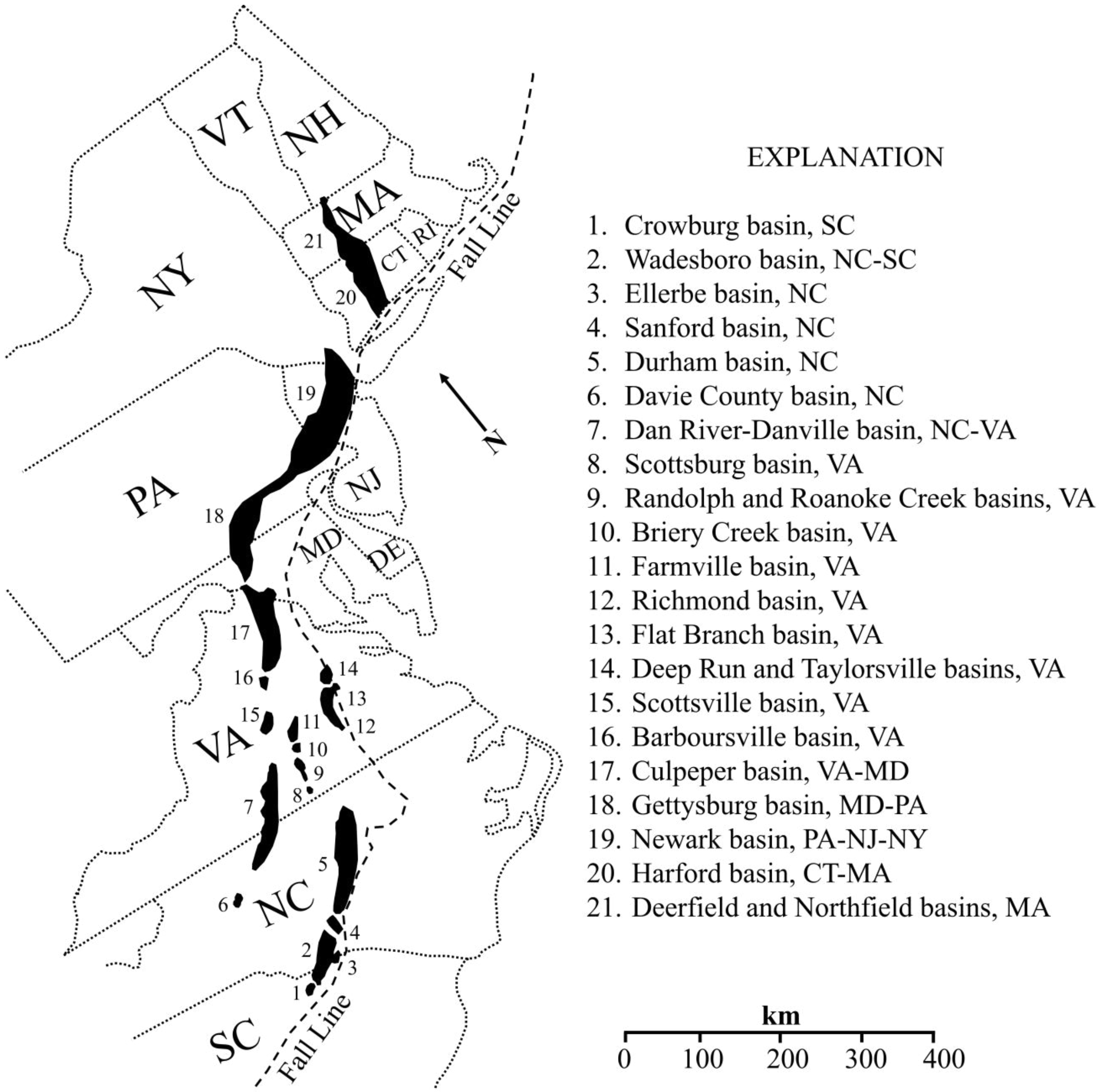

Figure 3.4. *Exposed basins of the Newark Supergroup in the United States. The "Fall Line" is the geomorphologic boundary between uplands dominated by basement rocks to the west and the coastal plain dominated by soft sedimentary rocks to the east. Modified from Figure 1, Luttrell (1989).*

The distribution of problematic RPM and their associated soils derived from the Newark Supergroup are shown in RPM guidance maps for the Northeast and Mid-Atlantic region (Figure 3.2). Table 3.8 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Newark Supergroup.

Table 3.8. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Newark Supergroup.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	R – Northeastern Forage and Forest	144A – New England and Eastern New York Upland, Southern Part 145 – Connecticut Valley
Eastern Mountains and Piedmont	N – East and Central Farming and Forest	130A – Northern Blue Ridge
	P - South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	136 – Southern Piedmont
	S - Northern Atlantic Slope Diversified Farming Region	148 – Northern Piedmont

Table 3.9 lists the soil series and geological formations identified as potential problematic RPM (included in RPM guidance maps) that are associated with the Newark Supergroup (see Figure 3.4 for reference).

Table 3.9. Geological formations and soil series identified as potential problematic RPM that are associated with basins of the Newark Supergroup.

Basin(s)	**Geological Formation(s)**	**Soil Series**	
Harford, Deerfield, Northfield	East Berlin Formation Mount Toby Formation New Haven Arkose Portland Arkose Portland Formation Shuttle Meadow Formation Sugarloaf Formation Turner Falls Sandstone	Bash Berlin Branford Brownsburg Cheshire Ellington Harford Holyoke	Ludlow Manchester Menlo Penwood Watchaug Wethersfield Wilbraham Yalesville
Newark	Boonton Formation Brunswick Formation Feltville Formation Hammer Creek Formation Lockatong Formation Passaic Formation Raritan Formation Stockton Formation Towaco Formation	Abbottstown Arendtsville Athol Bermudian Birdsboro Boonton Bowmansville Brecknock Bucks Buckingham Chalfont Croton Doylestown Dunellen Exway Greenbelt Haledon Joanna Klinesville	Knauers Lamington Lansdale Landsdowne Lawrenceville Lewisberry Lucketts Morven Nixon Norton Pascask Penn Quakertown Raritan Readington Reaville Rowland Springwood
Gettysburg	Gettysburg Conglomerate Gettysburg Formation Heidlersburg Member Gettysburg Shale Hammer Creek Conglomerate Hammer Creek Formation New Oxford Conglomerate New Oxford Formation		
Culpeper, Barboursville, Scottsville	Newark Supergroup – conglomerates, sandstones, siltstones, shales, mudstones	Aden Albano Arcola Ashburn Brentsville Calverton Catlett Clover Dulles Kelly	Leedsville Manassas Nestoria Oatlands Ott Panorama Rapidan Sudley Sycoline Totier
Crowburg, Wadesboro, Ellerbe, Sanford, Durham, Davie County, Dan River, Danville, Scottsburg, Randolph, Roanoke Creek, Briery Creek, Farmville	Chatham Group Cow Branch Formation Cumnock Formation Dan River Group Pekin Formation Pine Hall Formation Sanford Formation Stoneville Formation	Ayersville Belews Lake Brickhaven Carbonton Claycreek Creedmoor Easthamlet Granville Hallison Hasbrouck Hornsboro Lackstown Leaksville Mayodan	Meadows Mooshaunee Peakin Pinkston Pinoka Polkton Sheva Spray Stoneville Straightstone Wadesboro Warminster White Store Wolftrap

**Note - the Richmond, Flat Branch, Deep Run, and Taylorsville basins (collectively referred to as the Chesterfield basin) of the Newark Supergroup (#12-14, Figure 3.4) are not recognized as areas with problematic RPM. Therefore, use of the F21- Red Parent Material field indicator is not appropriate in these areas. Soil series in this table were listed based on the basin and the geological formations that they predominantly occur in association with, however, their occurrence is not necessarily restricted to them. Many soil series occur across multiple basins, and may be associated with several different formations.*

Newark Supergroup: F21 – Red Parent Material User Notes

Problematic RPM associated with the Newark Supergroup in the Harford, Deerfield, and Northfield basins occurs in USDA-NRCS MLRA 145 of the northern, glaciated portions of the Northeast and Mid-Atlantic region. Therefore, PRPM soils in these basins are recognized predominantly as dark-red colored glacial deposits from the last (Wisconsinan) glaciation of the Pleistocene, containing reworked materials from the underlying Supergroup geology of the area. The majority of the RPM area is on the nearly level floor of the Connecticut River Valley (MLRA 145), with potential RPM soils occurring in areas dominated by fine-textured (glacio)lacustrine sediments on lake beds (e.g. Berlin and similar soils), loamy tills on till plains and drumlins (e.g. Menlo, Watchaug, Wethersfield, Wilbraham, and similar soils), and very sandy to gravelly outwash deposits on outwash plains and terraces (e.g. Branford, Ellington, Manchester, Penwood, and similar soils). Problematic RPM also occurs along the Connecticut River as recent alluvial deposits overlying the region's traditionally glaciated surfaces (e.g. Bash and similar soils). PRPM soils in northernmost areas of the Newark basin (MLRA 144A) are also possible on landscapes dominated by glacial outwash types of deposits, influenced by the underlying Supergroup bedrock like that of PRPM soils in the Connecticut River Valley (MLRA 145) (e.g. Pascask, Watchaug, and similar soils).

PRPM soils in the remaining basins of the Newark Supergroup occur in the southern areas of the Northeast and Mid-Atlantic region, existing predominantly as residuum and/or colluvium deposits on sloping areas from Supergroup bedrock sources. PRPM soils in these areas can exist on a variety of landforms within the basins (hills, interfluves, depressions, etc.), and are predominantly differentiated from each other by their differences in morphological characteristics such as texture, rock fragment type and content, drainage class, and/or depth to bedrock. Waterbodies of the region's watersheds also produce alluvial deposits containing problematic RPM throughout the area, sourced from the residual and/or colluvial Supergroup bedrock materials in higher parts of the landscape (e.g. Albano, Belews Lake, Birdsboro, and similar soils).

In addition to the problematic, red-colored sedimentary rocks that characterize the Newark Supergroup, many sequences are also intruded and/or metamorphosed by diabase plutons, dikes, and basaltic flows (Luttrell, 1989). These materials also formed during Pangea rifting in the Mesozoic era as underlying magma seeped to the Earth's surface during continental divide (Olsen, 1980; Sutter, 1985). These igneous and metamorphosed materials are present in nearly all of the Supergroup basins, however, pedogenesis from these rocks produce soils that are typically more yellow-brown colored and non-problematic compared to soils derived from the red-colored sedimentary sequences. Therefore, soils derived from and/or influenced by these diabase and basaltic materials are not resistant to color change as required by the F21 – Red Parent Material indicator, and the locality of these diabase dikes and basaltic flows within the Newark Supergroup areas must be kept in mind when making F21 hydric soil determinations. Furthermore, some problematic RPM formations in the Culpeper-Barboursville basins contain metamorphosed, Triassic-aged shales known as horfels (Lee and Froelich, 1989). These rocks also produce non-problematic soils that are very dark in color (e.g. Catlett, Kelly, Sycoline and similar soils), however, these areas were included in RPM guidance maps not to miss other potential problematic RPM known to occur in similar areas.

Great Lakes Region

A total of 218 soil samples from 80 sites (~19% of the total 456 sites) were submitted and analyzed for CCPI from the Great Lakes region. Of these, 137 samples (64 sites) were provided from KSSL archives, 37 samples (13 sites) from USDA-NRCS soil scientists, and 8 samples (3 sites) from USACE field personnel. From these samples, problematic RPM has been identified for appropriate use of the F21 – Red Parent Material indicator in nineteen MLRAs of two major LRRs in the Northcentral and Northeast Regional Supplement Region defined by the USACE (Table 3.10).

Table 3.10. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas within this study's Great Lakes region where application of the F21 - Red Parent Material Indicator is appropriate.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	K – Northern Lake States Forest and Forage Region	57 – Northern Minnesota Gray Drift* 88 – Northern Minnesota Glacial Lake Basins* 89 – Wisconsin Central Sands 90A – Wisconsin and Minnesota Thin Loess and Till, Northern Part 90B - Wisconsin and Minnesota Thin Loess and Till, Southern Part 91A – Central Minnesota Sandy Outwash* 91B – Wisconsin and Minnesota Sandy Outwash 92 – Superior Lake Plain 93A – Superior Stony and Rocky Loamy Plains and Hills, Western Part 93B - Superior Stony and Rocky Loamy Plains and Hills, Eastern Part 94A – Northern Michigan and Wisconsin Sandy Drift 94B – Michigan Eastern Upper Peninsula Sandy Drift 94C – Michigan Northern Lower Peninsula Sandy Drift 94D –Northern Highland Sandy Drift 95A – Northeastern Wisconsin Drift Plain 95B – Southern Wisconsin and Northern Illinois Drift Plain
	L – Lake States Fruit, Truck Crop, and Dairy Region	96 – Western Michigan Fruit Belt+ 98 – Southern Michigan and Northern Indiana Drift Plain+ 99 – Erie-Huron Lake Plain+

**Note – Problematic RPM within MLRAs 57, 88, and 91A (indicated with a "*") are not mapped in RPM guidance maps for the Great Lakes region (Figure 3.5). See "Superior Lobe: F21 – Red Parent Material User Notes" sections for guidance on the use and application of the F21 – Red Parent Material field indicator in these areas. MLRAs indicated with a "+" lack sufficient CCPI data to identify the exact distribution and occurrence of RPM in these areas. See "Michigan Basin" and "Michigan Basin: F21 – Red Parent Material User Notes" sections for more information.*

A guidance map for the potential occurrence of problematic RPM, and therefore the appropriate application of field indicator F21 – Red Parent Material, in the Great Lakes region is shown in Figure 3.5.

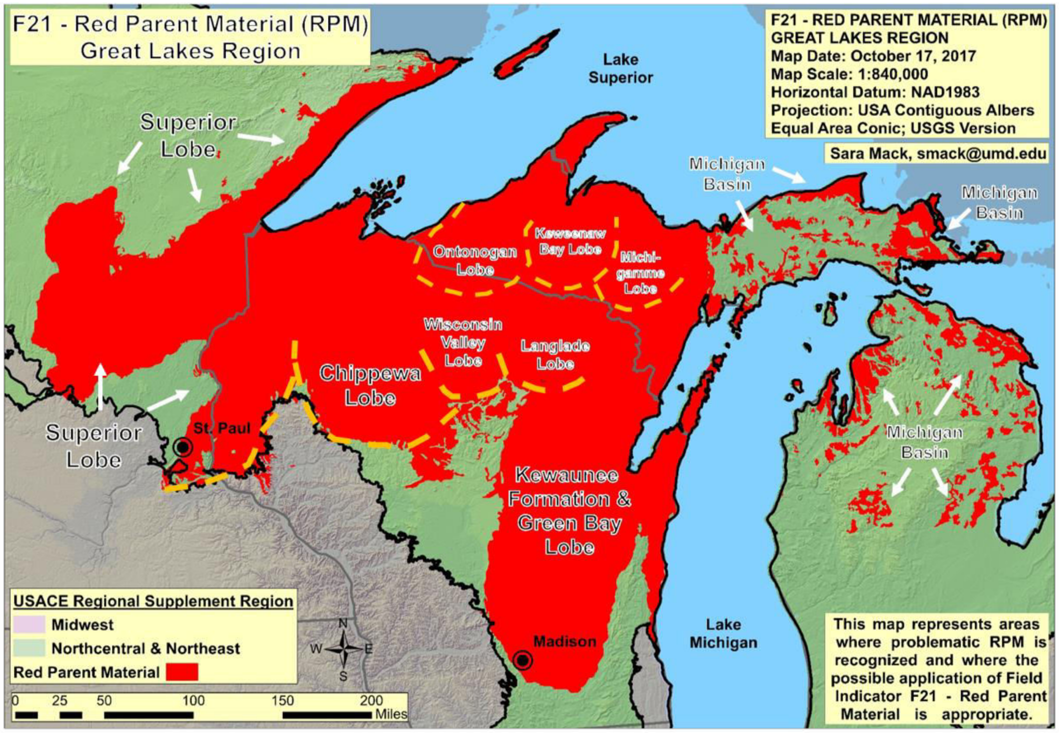

Figure 3.5. *Guidance map for appropriate application of the F21 - Red Parent Material (RPM) field indicator in the Great Lakes region. Red areas indicate locations with soils and geological formations where problematic RPM are possible. Note that suspected RPM soils in these areas must also meet current color requirements of the F21 field indicator for application.*

Problematic RPM in the Great Lakes region is derived almost entirely from Pleistocene-aged, glacial deposits that stretch across portions of three U.S. states: Michigan, Minnesota, and Wisconsin. This glaciation occurred within the Superior Upland and northern portions of the Central Lowland physiographic provinces. Areas with problematic RPM are differentiated across the landscape based on their association with distinct “tongues” or “lobes” of the Laurentide ice sheet, shaped by localized changes in climate, precipitation, etc. as the ice retreated north from its southernmost extent at glacial climax of the Wisconsinan glaciation between 25-21 Kya (Lusardi, 1997). PRPM soils, deposited by these glacial fronts, are possible to occur on a wide variety of glacial landforms (moraines, drumlins, outwash plains, lake beds, etc.), however, landscape patterns in specific areas are “footprints” indicative of the directions the glaciers advanced and retreated to sculpt the overall region. Three distinctive groups of soils and parent materials, associated with the growth and retreat of the ice, have been identified where the F21 – Red Parent Material indicator may be applied:

1. Soils derived from reddish-colored glacial deposits associated with the Superior Lobe of eastern MN, northwestern WI, and the northwestern sections of the upper peninsula of MI.
2. Soils derived from reddish-colored glacial deposits of the Kewaunee formation associated with the Green Bay and Lake Michigan Lobes of eastern WI; and
3. Soils derived from reddish-colored glacial till and (glacio)lacustrine deposits distributed across the east upper and north lower peninsulas of MI within the Michigan Basin.

The following sections describe the nature of the groups of soils and parent materials that are recognized as problematic RPM (including soil series and geological formations suggested to be source rocks of the glacial deposits). These areas are also highlighted on RPM guidance maps showing where the indicator may be applied. Where appropriate, additional guidance on use and application of the F21 – Red Parent Material indicator is given as “user notes.”

Superior Lobe

Problematic RPM of this group in the Great Lakes region are derived from glacial drift and morainic systems deposited by the Superior Lobe that once covered northeastern MN, northern WI, and northwestern parts of the upper peninsula of MI at the height of the Wisconsinan glaciation in the Pleistocene (Figure 3.5, 3.6).

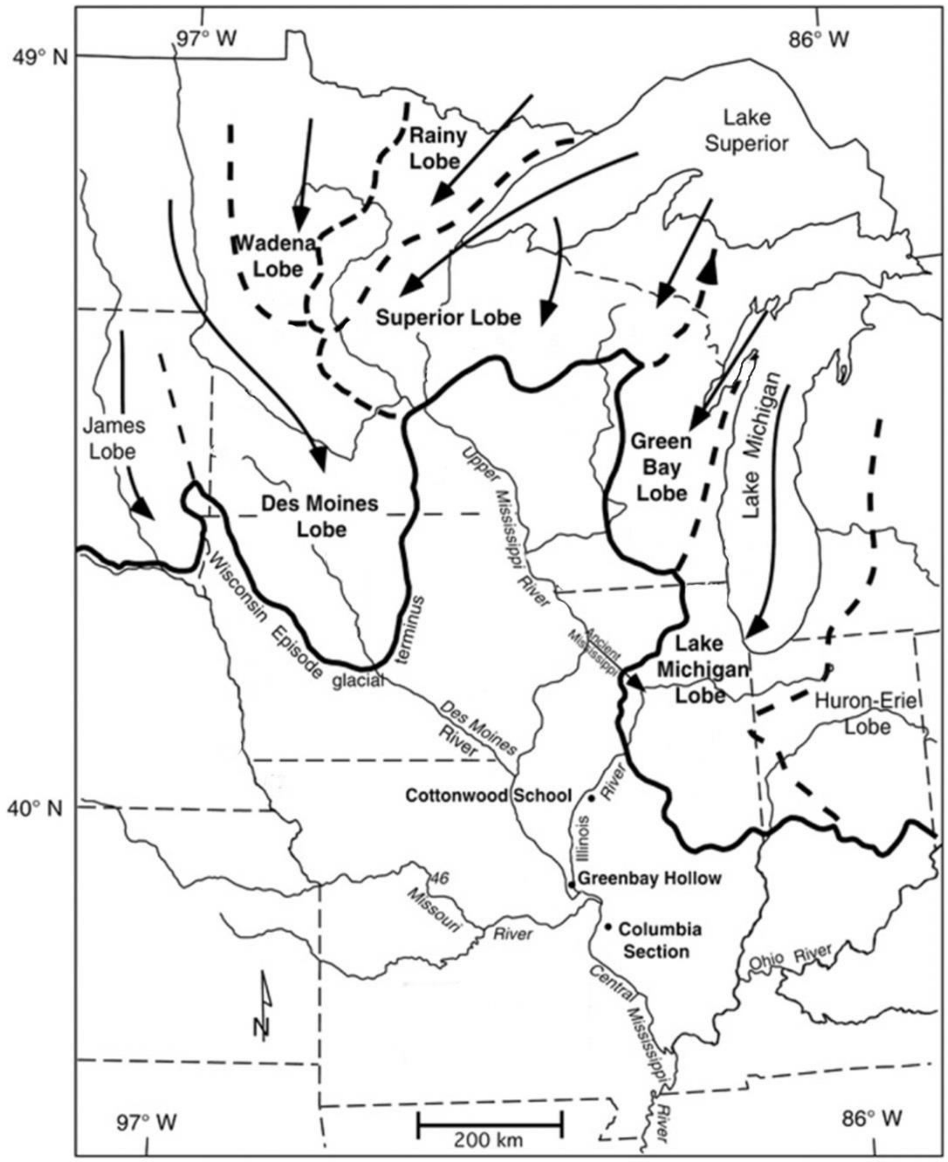

Figure 3.6. *Major ice lobes of the Laurentide Ice Sheet at the height of the Wisconsinan glaciation. The Superior Lobe advanced from the northeast to southwest across the Superior Basin currently occupied by Lake Superior. Modified from Figure 2, Grimley (2000).*

This major glacial advance is further subdivided into a series of sublobes called the Chippewa, Wisconsin Valley, and Langlade lobes in northern WI (Figure 3.7, A and B), and the Ontonogan, Keweenaw Bay, and Michigamme lobes in northwestern parts of the upper peninsula of MI (Figure 3.7, C).

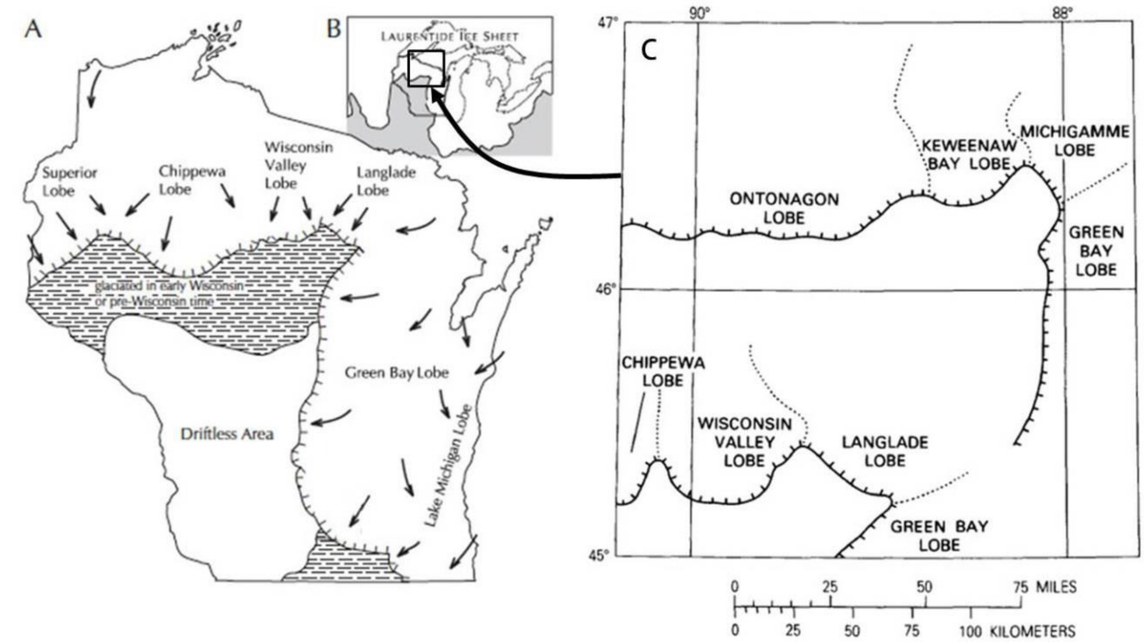

Figure 3.*7. Chippewa, Wisconsin Valley, and Langlade subdivisions of the Superior Lobe in northern WI (A) in relation to the Laurentide Ice Sheet (B) at the height of the Wisconsin Glaciation. Ontonagon, Keweenaw Bay, and Michigamme subdivisions of the Superior Lobe occur in the northern peninsula of MI (C) and represent the extent of ice as the glaciers retreated north towards the end of the Wisconsinan. Figure A and B modified from Figure 1, Clayton and Attig (1997). Figure C modified from Figure 2, Peterson (1986).*

At glacial maximum, each lobe was welded together south of the Great Lakes region as one broad glacier as they advanced southward over the region. Only when the ice began to melt north did the large ice front separate into distinct lobes (Lusardi, 1997).

While subdivided across the Great Lakes region, tills and glacial sediments of the Superior Lobe are differentiated from those of other glacial advances (Rainy, Des Moines, etc., see Figure 3.6) by their characteristic red color (Lusardi, 1997; Peterson, 1982; Peterson, 1986). The source of the red color of the sediments, however, is debatable since the bedrock underlying most of the glacial deposits in the area are dark-colored, mid-to-late Precambrian-aged (2500-600 Mya) rocks of the Canadian Shield (Bornhorst, 2016). This shield (that makes up the core of the North American Craton, Laurentia), is an assemblage of mostly igneous, meta-volcanic, and metasedimentary rocks formed via accretion and orogeny that occurred over the span of the Precambrian era between 4000 and 540 Mya (Card, 1990; Bornhorst, 2016).[47] Formations from this time frame thus represent a variety of tectonic events and depositional environments of the early Earth, including: Archean-aged granites, gneisses, and volcanogenic sulfide and iron deposits that formed the first basement rocks of Laurentia (Bornhorst, 2016; Ojakangas and Matsch, 1982), Paleoproterozoic-aged, sedimentary banded-iron formations that mark the evolution of photosynthesis on Earth (Bray, 1977), and the basaltic flows of the Keweenawan Supergroup formed during the Mid-Continental Rift in the Neoproterozoic (Cannon and Nicholson, 1970; Ojakangas and Matsch, 1982; Halls, 2013). These rocks have since been uplifted and/or altered by bouts of volcanic activity and metamorphism as the Canadian Shield accreted land mass over time (Ojakangas and Matsch, 1982).

The tills of the Superior Lobe and its sublobes, however, are believed to be derived from Mesoproterozoic (~1.1 Bya) to early Cambrian-aged (540 Mya), red-colored, conglomerates, sandstones, shales, and agates found in the Superior Basin portion of the Shield (Halls and West, 1971; Dell, 1972; Dell, 1975; Lineback et al., 1979; Ojakangas and Matsch, 1982; Peterson, 1982; Peterson, 1986; Baumann, 2010). These sedimentary rocks originated as eroded materials from mountains formed after the Penokean orogeny when an ancient oceanic arc collided with the southern margin of the Archean craton in the Paleoproterozoic (~1880 Mya) (Schulz and Cannon, 2007; Meyers, 2008). These eroded materials were terrestrially

[47] The Canadian Shield stretches north from the Great Lakes to the Arctic Ocean and contains the world's oldest rocks. Millions of years of erosion by tectonic movement, rivers, glaciers, etc. since formation have changed the jagged peaks and mountains that once characterized the shield into flatter, broader rolling hills where parts of the shield are exposed at the surface (Card, 1990).

deposited in fluvial, deltaic, and lacustrine environments as the sediments washed northward out of the highlands and accumulated in a moist, humid climate (Rose, 1997; Eckert, 2000). In the United States, this bedrock, from which the red colors of the Superior Lobe sediments are derived, extend throughout the northernmost portions of the upper peninsula of MI bordering Lake Superior (Hamblin, 1958; Michigan Geological Survey, 1987), the northwestern tip of WI just south of Lake Superior (Wisconsin Geological and Natural History Survey, 2006), underlies the majority of the Superior Lake Basin and eastern MN (Halls and West, 1971; Jirsa et al., 2011), and is the source of the current lake bed sediments under Lake Superior (Dell, 1972) (Figure 3.8).

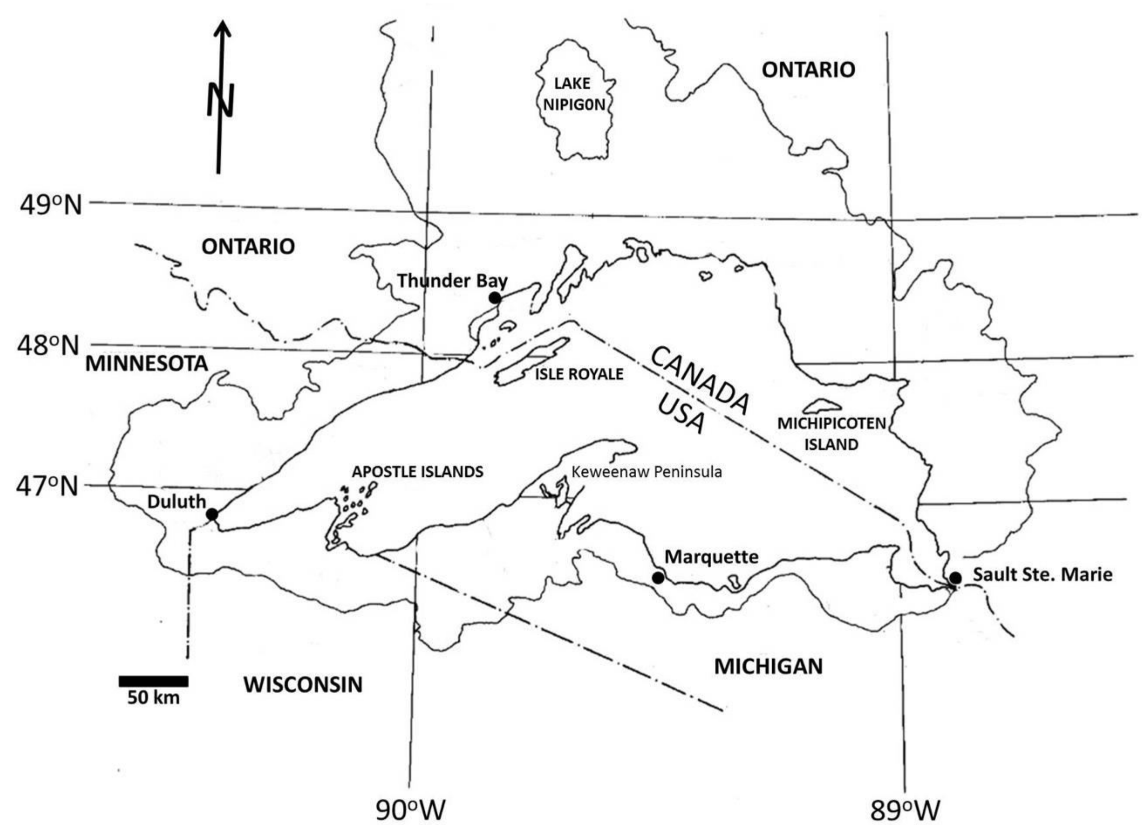

Figure 3.8. *Generalized boundaries of the Superior Basin in the northern United States and southern Canada. This basin is contained entirely within the structural boundaries of the Canadian Shield. Modified from Figure 1, Matheson and Munawar (1978).*

In the overall Great Lakes region where RPM occurs as associated with the Superior Lobe, little to none of the bedrock following the early-Cambrian era remains (Bornhorst, 2016), with the exception of some late-Cambrian-aged dolomite and sandstone units found in northwestern WI (Wisconsin Geological and Natural History Survey, 2006).

More recently in the Pleistocene (~2 My to 12 Kya), the Great Lakes region experienced four major episodes of glaciation: the Nebraskan (~2 Mya), Kansan (~400 Kya), Illinoian (~150-120 Kya), and the Wisconsin (~85-10 Kya), separated by bouts of warmer interglacial intervals (Ojakangas and Matsch, 1982; Bray, 1977).[48] During each glaciation, various lobate fronts of ice scoured old soil surfaces and underlying bedrock, depositing new mixtures of materials and carving depressions, drainages ways, etc. into the landscape that would eventually be occupied by meltwaters as the ice retreated. While the Great Lakes region experienced multiple phases of glaciation in the Pleistocene, most glacial materials are interpreted to be deposited by and/or derived from the lobate fronts of the most recent Wisconsinan glaciation. Some glacial deposits older than the Wisconsinan are present in central Wisconsin (Clayton et al., 2006; Syverson and Colgan, 2004) and in the subsurface in some locations of northeastern MN and northwestern WI (Bray, 1977; Syverson and Colgan, 2004), however, these deposits have received little study (Lehr and Hobbs, 1992; Ojakangas and Matsch, 1982), and are not considered to be problematic RPM.

[48] The Nebraskan glaciation advanced into central U.S. as far south St. Louis; the Kansan advanced similarly in direction and extent as the Nebraskan with drift stretching wider across Kansas; the Illinoian advanced into east-central U.S. to cover almost all of Illinois (presence of ice from this glaciation is less certain in the west-central parts of the U.S); and finally the Wisconsin glaciation advanced similarly as the Illionoian, but only as far south as central Illinois (Ojakangas and Matsch, 1982; Bray, 1977).

Furthermore, during the Wisconsinan, the lobate fronts of ice in the region advanced relative to each other in several phases, determined by the extent of the types of materials that were deposited and the moraines that were left behind. Specific to the Superior Lobe in MN, its largest advance occurred during the Hawk Creek phase (35 Kya), covering all of southern portion of the state (Bray, 1977).[49] Advances and deposition of other lobes from differing directions have since buried Superior Lobe till and/or mixed Superior Lobe till with tills of other ice lobes to form its current distribution. In MN specifically, during the Itasca and St. Croix phases (~20.5 Kya), the Superior Lobe combined with the Rainy Lobe to form the sharply defined St. Croix moraine that marks the current southern extent of the till south of the Twin Cities and then east into WI (Bray, 1977). During the Automba and Vermilion phases (20-16 Kya), parts of the Superior Lobe advanced into areas vacated by the Rainy Lobe and formed the Mille Lacs-Wright-Cromwell-Highland moraine complex that marks the current extent of Superior Lobe till in the northeastern and south-central parts of MN (Bray, 1977; Lusardi, 1997; Hobbs and Goebel, 1982) (Figure 3.9).

[49] During this phase, red materials from the Superior Basin are also believed to have been carried as far west as the Coteau des Prairies in eastern South Dakota (Bray, 1977). No problematic RPM associated with glacial deposits has been identified in South Dakota to date.

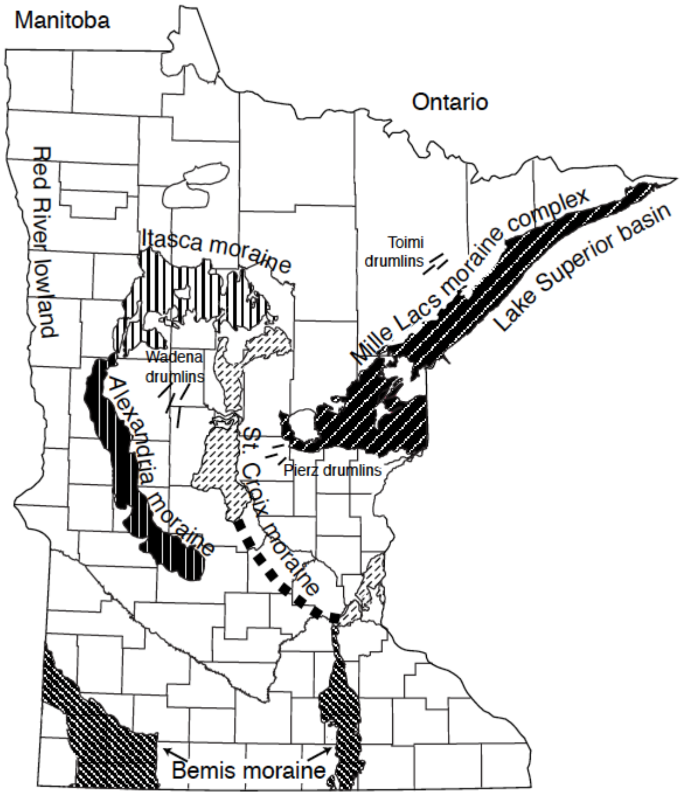

Figure 3.9. *Simplified quaternary geology map of Minnesota showing the locations of major end moraines (dashed where inferred) and locations and orientations of drumlin fields. Problematic RPM is associated with the deposits of the Mille-Lacs moraine complex and parts of the St. Croix moraine in south-central Minnesota. Figure 3B from Lusardi (1997).*

Areas originally covered by Superior Lobe till in the central and southern parts of the state were eventually buried by ice and sediments of the Des Moines Lobe (and St. Louis and Grantsburg sublobes) from the northwest during the Pine City and New Ulm phases (16-14 Kya) (Bray, 1977; Hobbs and Goebel, 1982). Likewise, in WI, numerous phases of glaciation by the Chippewa, Wisconsin Valley, and Langlade sublobes left a series of moraines across northern WI that mark changes in the extent of the ice, however, each sublobe front tended to advance in similar south-southwest directions (Peterson, 1986; Clayton et al., 2006; Syverson and Colgan, 2004), compared to MN where lobes of ice had crisscrossing paths as they advanced and retreated over the region (Bray, 1977; Lusardi, 1997).

The terminal moraines of the Wisconsinan glaciation that mark the southernmost extent of each of these sublobes in WI are collectively known as the Woodfordian moraines[50] (Peterson, 1986; Syverson and Colgan, 2004), and also represent the maximum extent of the Ontonagon, Keweenaw Bay, and Michigamme sublobes in MI at their maximum extent during the late Woodfordian as the ice receded northward (12-14 Kya) (Frye et al., 1968; Peterson, 1986) (see Figure 3.7, C). Tills associated with the retreat of these sublobes (especially in WI), have been further divided into surficial formations based on differing characteristics of the tills (Clayton et al., 2006; Syverson and Colgan, 2004) (Figure 3.10).

Figure 3.10. *Surficial geology for glacial till deposited by lobate fronts of ice in Wisconsin during the Pleistocene. Problematic RPM is primarily associated with glacial deposits of the late-Wisconsinan glaciation (30 Kya to present). Figure 4 from Syverson and Colgan (2004).*

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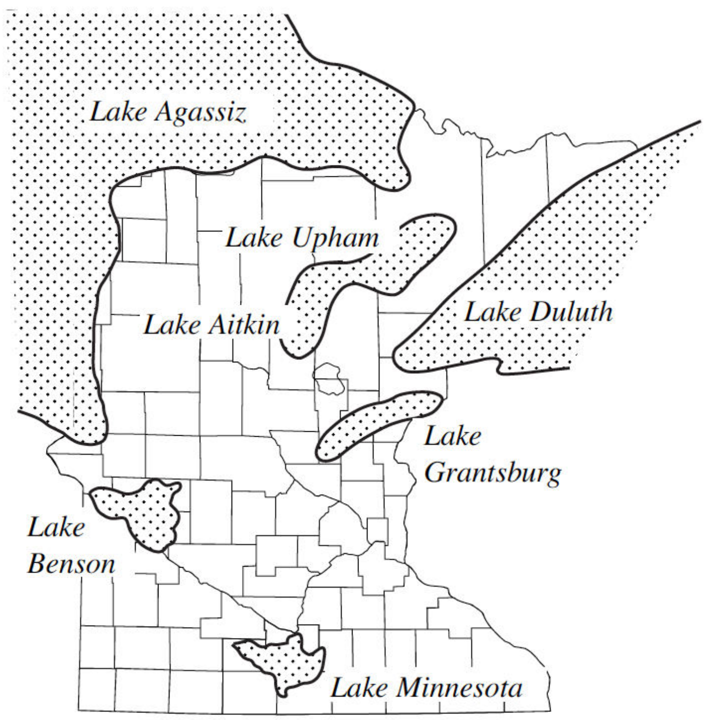
[50] The Chippewa, Wisconsin Valley, Harrison, Parrish, Summit Lake, and Outer terminal moraines that mark the extent of Wisconsinan glaciation during the Pleistocene in northern WI are collectively referred to as the Woodfordian moraines (Peterson, 1986).

Finally, as the end of the Wisconsinan was approaching, several large proglacial lakes were formed in the various phases of glacial retreat from melting ice. Many of these ancient lakes have now completely disappeared by drainage through river networks, exist only as small remnants, or have become part of the current Great Lake water bodies (Bray, 1977; Ojakangas and Matsch, 1982; Peterson, 1986; Lusardi, 1997). Ancient lake bed deposits associated with the Superior Lobe and/or Superior Basin are those of Lake Upham, Aitkin, and Duluth in MN (Bray, 1977) (Figure 3.11), as well as the remnants of a series of proglacial lakes that mark the ancient extent of both modern-day Lake Superior and Lake Michigan in northern WI and the upper peninsula of MI (Lake Duluth, Houghton, Minong, Algonquin, parts of the Nipissing Great Lakes, etc.).[51]



[51] For more information and discussion on the proglacial lakes of the Superior Lake Basin in MN, northern WI and MI, see Leverett (1929); Farrand (1960); Huber (1973); Farrand (1988) and Larson and Schaetzl (2001), amongst others.

Figure 3.11. Generalized locations of pro-glacial lakes formed from the melt out of glaciers at the end of the Wisconsinan glaciation in Minnesota (these lakes are not necessarily contemporaneous). Problematic RPM has been found to be associated with deposits from Lake Aikin, Upham, and Duluth. Figure 4 from Lusardi (1997).

Many smaller proglacial lakes beds containing Superior Lobe materials are also recognized throughout north-central parts WI (MLRAs 90B and 91B) (Ojakangas and Matsch, 1982).[52]

The distribution of problematic RPM and their associated soils of the Superior Lobe are shown in RPM guidance maps for the Great Lakes region (Figure 3.5). Table 3.11 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Superior Lobe.

Table 3.11. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Superior Lobe.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	K – Northern Lake States Forest and Forage Region	57 – Northern Minnesota Gray Drift* 88 – Minnesota Glacial Lake Basins* 89 – Wisconsin Central Sands* 90A – Wisconsin and Minnesota Thin Loess and Till, Northern Part 90B – Wisconsin and Minnesota Thin Loess and Till, Southern Part 91A – Central Minnesota Sandy Outwash* 91B – Wisconsin and Minnesota Sandy Outwash 92 – Superior Lake Plain 93A – Superior Stony and Rocky Loamy Plains and Hills, Western Part 93B – Superior Stony and Rocky Loamy Plains and Hills, Eastern Part 94B – Michigan Eastern Upper Peninsula Sandy Drift 94D – Northern Highland Sandy

**Note – Problematic RPM within USDA-NRCS MLRAs 57, 88, 89, and 91A are largely not mapped in RPM guidance maps for the Great Lakes region (Figure 3.5). See "Superior Lobe: F21 – Red Parent Material User Notes" sections for guidance on the correct use and application of the F21 – Red Parent Material field indicator in these areas.*

[52] Parts of proglacial Lake Wisconsin are also within these MLRAs in northcentral WI; however, this lake is associated with deposits from older Pre-Wisconinan glaciations (USDA-NRCS, 2006) that are not considered to be problematic RPM.

Table 3.12 lists the soil series and geological formations identified as potential problematic RPM (included in RPM guidance maps) that are associated with the Superior Lobe.

Table 3.12. Geological formations and soil series identified as potential problematic RPM that are associated with the Superior Lobe.

Geological Formation(s)	Soil Series			
Bayfield Group	Adolph	Ellsburg*	Matchwood	Poskin
Chequamegon Sandstone	Ahmeek	Escanaba	McQuade*	Richford
Devil's Island Sandstone	Aldenlake	Fayal*	Mecan	Robago
Orienta Sandstone	Algonquin	Fence	Mesaba	Rockland
Chippewa Lobe Till	Allendale	Finland	Michigamme	Rockmarsh
Copper Falls Formation*	Amery	Flak	Milaca	Ronneby
Fond du Lac Formation	Amnicon	Flink	Millward	Rosholt
Hinckley Sandstone	Anigon	Flintsteel	Misery	Rudyard
Jacobsville Formation	Annalake	Forbay	Mishwabic	Sanborg
Jacobsville Sandstone	Anton	Freeon	Miskoaki	Santiago
Keweenaw Bay Lobe Till	Arcadian	Freer	Montreal	Schaat Creek
Langlade Lobe Till	Arnheim	Froberg	Mooseline*	Schisler*
Lincoln Formation*	Ashwabay	Gaastra	Moquah	Schweitzer
Michigamme Lobe Till	Augustana	Garlic	Mora	Scoba
Miller Creek Formation*	Automba	Gay	Morganlake	Sconsin
Ontonagon Lobe Till	Baden+	Giese	Munising	Sedgewick
Oronto Group	Badriver	Glendenning	Negwegon	Shag
Copper Head Conglomerate	Barto	Gogebic	Nemadji	Skanee
Freda Sandstone	Bergland	Gratiot	Net	Spear
Nonesuch Shale	Big Iron	Greenstone	Newood	Sporley
River Falls Formation*	Bigisland	Gull Point	Newot	Springport
Superior Lobe Till	Borea	Haugen	Nonesuch	Springstead
Trade River Formation*	Brennyville	Haybrook	Normanna	St. Francis
Wisconsin Valley Lobe Till	Brill	Hegberg	Ocqueoc	Sturgeon
	Bushville	Hellwig+	Odanah	Superior
	Canosia	Herbster	Ogilvie	Tipler
	Carp Lake	Hermantown	Oldman	Toimi+
	Cebana	Hibbing+	Omega	Trap Falls
	Chequamegon	Hulligan+	Ontonagon	Trimountain
	Chetek	Jewett	Oronto	Tula
	Chippewa	Karlin	Ossmer	Turpela
	Harbor	Kellogg	Otterholt	Twig
	Clemens	Keweenaw	Paavola	Wabeno
	Copper	Kingsley	Padus	Wahbegon
	Harbor	Lac La Belle	Padwood	Waiska
	Cornucopia	Langola	Palmers	Wakefield
	Cress	Lerch	Parent	Watab
	Cromwell	Loggerhead	Payseor	Watton
	Culver+	Magnor	Pearl	Worchester
	Cuttre	Mahtowa	Pelkie	Wormet
	Dairyland	Majestic+	Pemene	Worwood
	Dechamps	Makwa	Pence	Yalmer
	Denomie	Manido	Pesabic	
	Dinham+	Manistee	Peshekee	
	Duluth	Manitowish	Pickford	
	Dusler		Porkies	
	Eaglebay		Portwing	
	Eldes			

Note – Geological formations indicated with an "" are surficial formations given to names of the Wisconsinan-aged tills mapped primarily in northern WI (not formations pertaining to underlying bedrock) (Lusardi, 1997) (USDA-NRCS, 2006) (see Figure 3.10). Soil series indicated with an "+" are those that occur in MLRA 88 – Minnesota Glacial Lake Basins - where the landscape is derived from proglacial lake bed sediments of Lake Aikin and Upham and reworked materials deposited by the St. Louis sublobe towards the end of the Wisconsinan glaciation (Clayton et al., 2006; Bray, 1977; Ojakangas and Matsch, 1982; Lusardi, 1997) (see Figure 3.11). See "Superior Lobe: F21 – Red Parent Material User Notes – Lake Aitkin and Upham" section for guidance on the correct use and application of the F21 – Red Parent Material field indicator with these soil series.*

Superior Lobe: F21 – Red Parent Material User Notes

While all PRPM soils associated with the Superior Lobe are characteristically red in color, several groups of soils have additional characteristics distinctive to specific areas and the types of the landforms (moraines, outwash plains, etc.) deposited by the glacier. Generally, PRPM soils derived from glacial materials of the Superior Lobe tend to be finer textured in MN and areas nearest to Lake Superior, while the soils of the Superior sublobes across north-northcentral WI and upper MI tend to be sandier and more podzolized[53] (Peterson, 1982). Within this overall area, several major groups of PRPM soils are distinguishable amongst all materials derived from the Superior Lobe. They are: soils of the Mille Lacs-Wright-Cromwell-Highland moraine complex; soils of the Superior Lake Plain; soils of the Chippewa, Wisconsin Valley, and Langlade sublobes; soils of the Ontonagon, Keweenaw Bay, and Michigamme sublobes; soils derived from sediments of proglacial Lake Aikin and Upham; and soils derived from recent alluvium of river networks that drain and transport glacial materials deposited by the Superior Lobe throughout the region. A general description of these groups of PRPM soils is provided in the following F21 – Red Parent Material "user notes" for the Superior Lobe deposits.

[53] Podzolization, in general, is a process of soil formation in which iron and aluminum oxides, in combination with soil organic matter from the soil surface, are accumulated in the subsurface of the soil profile. This process is characteristic of soils classified as Spodosols. For more information on podzolization and/or the characteristics of Spodosol soils, see Soil Survey Staff, USDA-NRCS (2014).

Mille-Lacs-Wright-Cromwell-Highland-Moraine Complex

PRPM soils of the Mille Lacs-Wright-Cromwell-Highland moraine complex occur in northeastern MN adjacent to Lake Superior (easternmost portions of MLRA 93A) and in central MN (MLRAs 90A/B) (Figure 3.5, 3.9). PRPM soils in both these areas occur on gently rolling moraines and till plains as fine-to-coarse loamy, poorly sorted (gravelly, cobbly, stony, etc.) tills underlain by firm, dense till at depth. Soils representative of these tills in eastern MN (MLRA 93A) are the Ahmeek, Augustana, Eldes, Hegberg, Normanna, and similar soils; and soils representative of these tills in central MN (MLRAs 90A/B) are the Automba, Cebana, Dusler, Freer, Mora, and similar soils. Adolph, Giese and similar soils occur in concave, low-lying, flat, and/or depressional areas on the moraines. Throughout both these areas, these PRPM soils are also mapped on drumlins formed in association with the Mille-Lacs-Wright-Cromwell-Highland moraines.

In easternmost MN (MLRA 93A), however, many poorly-sorted tills are moderately deep-to-shallow to bedrock, occurring on complex bedrock-controlled surfaces underlain by non-problematic rocks (gabbro, basalts, and granites) (e.g. Barto, Greysolon, Mesaba and similar soils). Some vertic, very-fine soils derived from clayey lacustrine deposits also occur on knolls and flats of tills plains between moraines (e.g. Sanborg, Palmers, and similar soils). In central MN, PRPM soils may be also be mixed with non-problematic materials from the Rainy Lobe[54] (MLRA 57). These soils tend to occur with/as coarse-textured, skeletal (extremely gravelly, cobbly, etc.), glaciofluvial and/or outwash deposits on convex outwash plains and

[54] In comparison to tills of the Superior Lobe, tills of the Rainy Lobe are characteristically sandier, browner in color, and derived from basalt, gabbro, greenstones, and other metasediments (Lusardi, 1997; Ojakangas and Matsch, 1982) that are not recognized as problematic RPM.

valley trains in areas that grade out of landscapes dominated by loamy morainic deposits of the Mille-Lacs-Wright-Cromwell-Highland moraine complex (e.g. Brainerd, Bushville, Chetek, Cloquet, Cromwell, Culver, and similar soils). Others tills mixed with Rainy Lobe materials are coarse-loamy to sandy tills on drumlins and moraines associated with St. Croix moraine (e.g. Flak, Mahtomedi, Nokay, Prebish, Watab and similar soils) in central MN. These parts of the St. Croix moraine have been lumped with the Mill-Lacs-Wright-Cromwell-Highland moraine complex in RPM guidance maps in central MN (Figure 3.5, 3.9).

Finally, amongst all soils of these morainic systems, a browner, finer-textured "mantle" of eolian and/or water laid materials (that are not problematic RPM) commonly blankets the problematic glacial materials deposited by the Superior Lobe. Organic materials (i.e. histic epipedons) also overly problematic RPM in concave, shallow depressions, drainageways, and swales between moraines and drumlins in the area (e.g. Blackhoof, Cathro, Twig, Rifle and similar soils). In these cases, other Field Indicators may be more useful in delineating hydric soils, however, these areas were included in RPM guidance maps not to miss areas with potential problematic RPM where the F21 – Red Parent Material field indicator could be applied.

Superior Lake Plain

PRPM soils of the Superior Lake Plain (MLRA 92) occur in northern WI and the upper peninsula of MI beneath Lake Superior (Figure 3.5). These areas are mapped on the Miller Creek formation in WI (Clayton et al., 2006; Syverson and Colgan, 2004; Syverson et al., 2011) (Figure 3.10), and correspond to the historic extent of proglacial Lake Duluth and the subsequent proglacial lakes that eventually drained into the current shorelines of Lake Superior (Farrand, 1960; Larson and Schaetzl, 2001; Huber, 1973) (Figure 3.12).

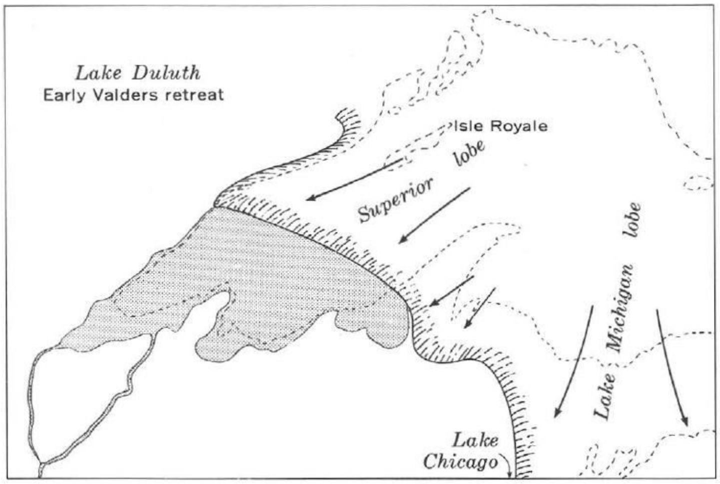


Figure 3.12. *Generalized schematic of glacial lake Duluth relative to the contemporary ice border approximately 11.5 Kya. The dashed line represents the shorelines of today's Great Lakes (Lake Superior & Michigan). The shaded areas beyond the boundary of Lake Superior's shorelines roughly corresponds to the extent of the area of the Superior Lake Plain (MLRA 92) in eastern MN, northern WI, and the northwestern parts of the upper peninsula of MI. Figure 10 from Huber (1973).*

Soils in this Superior Lake Plain (MLRA 92) are especially clayey, mapped as very fine, vertic, and sometimes calcareous lake sediments and/or till deposits on nearly level till and lake plains (e.g. Badriver, Cuttre, Matchwood, Odanah, Sanborg, and similar soils). Many soils in this Lake Plain are also stratified, sometimes sandy, and interpreted as relict lake shorelines modified by wave action by proglacial Lake Duluth (e.g. Herbster, Kellogg, Lerch, Superior, and similar soils). In some cases, sandy surface materials are not as red, however, they commonly overly dark-red, finer-textured lacustrine materials that are problematic RPM in the subsurface (e.g. Allendale, Ashwabay, Manistee, Kellogg and similar soils).

Furthermore, some loamy tills underlain by dense till (sourced from the red sedimentary bedrock of the Superior Lake Basin) occur on knolls, rises, and sideslopes of moraines and till plains (e.g. Big Iron, Carp Lake, Flint Steel, Gichigami, Loggerhead, and similar soils). Some of these loamy tills even overlie the problematic red bedrock of Superior Basin near the current shorelines of Lake Superior (e.g. Greenstone, Mishwabic, Nonesuch, and similar soils). Finally, outwash deposits are also recognized on outwash plains and fans in southernmost areas grading out of the Superior Lake Plain (MLRA 92).

Chippewa, Wisconsin Valley, and Langlade Sublobes

PRPM soils of the Chippewa, Wisconsin Valley, and Langlade sublobes occur on all of the types of glacial landforms distributed across northern WI (MLRAs 90A/B, 91B, 94D) (Figure 3.5). These glaciated areas correlate to the Copper Falls, River Falls, and Lincoln formations deposited by the Superior Lobe and its sublobes during the Wisconsinan glaciation (Clayton et al., 2006; Syverson and Colgan, 2004; Syverson et al., 2011) (Figure 3.10). Specifically, in MLRAs 90A/B, PRPM soils occur predominantly on gently undulating to rolling till plains, drumlins, moraines, outwash plains, and lake plains. PRPM soils on moraines (ground, terminal, end, etc.) and drumlins are typically loamy and poorly-sorted (gravelly to cobbly). Generally, in the west and west-central parts of northern WI, glacial tills of these moraines and drumlins are somewhat finer textured and contain and/or are underlain by dense till (Chequamegon, Freeon, Newood, Santiago, and similar soils). In the east and east-central areas in northern WI, tills are sandier, are not underlain by dense till, and podzolized (e.g. Keweenaw and similar soils). Tills characteristic of the St. Croix moraine that extends from central MN into northwestern WI are also poorly-sorted, finer-textured, and typically underlain by dense till (e.g. Amery, Cebana, Glendenning, Haugen, Jewett, Kinglsey, Spencer, and similar soils).

PRPM soils derived from outwash and glaciofluvial-type deposits are characterized as stratified, sandy, and skeletal (extremely gravelly, cobbly, etc.), occurring on outwash plains, kames, valley trains, terraces, etc. (e.g. Anigon, Brill, Cress, Emmert, Karlin and similar soils). In MLRAs 91B and 94D, PRPM soils are particularly outwash, mudflow, and/or ice-contact stratified drift deposits on outwash plains, kames, terraces and eskers (e.g. Stambaugh, Tipler, Wabeno, Wormet, and similar soils). While characterized by non-problematic Pre-Wisconsinan glacial deposits (between 2.4 Mya and 25 Kya), MLRA 89 – Wisconsin Central Sands can have some outwash and/or (glacio)lacustrine and fluvial types deposits from the more recent Wisconsinan glaciation (USDA-NRCS, 2006) that may be problematic RPM (e.g. Mecan, Pearl, Richford, and similar soils). Old stream terraces and recent alluvial deposits are closely associated with these outwash deposits.

Furthermore, some soils derived from lacustrine sediments are also recognized. These are also stratified like that of outwash and/or glaciofluvial deposits, but are more coarse-silty to fine in texture (e.g. Fence, Gaastra, Robago, Santiago, Worwood, and similar soils). Some problematic glacial tills, particularly in MLRA 90B, are also underlain by residual materials derived from Cambrian-aged sandstones and Precambrian-aged metamorphic and igneous bedrock (that are not recognized as problematic RPM) on bedrock-controlled uplands (e.g. Arland and similar soils).

Finally, throughout all areas associated with the Superior sublobes in northern WI, problematic RPM tends to be blanketed by a browner/yellower “mantle” of other silty or loamy materials (loess, alluvium, lake sediments, etc.) that are not problematic RPM. Generally, these browner mantles are deeper to problematic RPM

(50 to 100 cm) in MLRA 90B compared to brown mantles in MLRA 90A (0 to 50 cm). Soil series where these brown loamy mantles are recognized were included in RPM guidance maps for the Great Lakes region (Figure. 3.5) not to miss areas with potential problematic RPM where the F21 – Red Parent Material field indicator could be applied. It should also be noted that multiple types of problematic RPM glacial deposits (i.e. poorly sorted tills characteristic of moraines, gravelly/sandy materials of outwash plains, silty-stratified deposits of lake beds, etc.) can all occur within a single pedon (to a depth of ~ 1 meter) in these areas (e.g. Sconsin, Padwood, and similar soils). This is likely the result of cyclic deposition of glacial materials as the glaciers receded northward towards Canada at the end of the Wisconsinan glaciation.

Ontonagon, Keweenaw Bay, and Michigamme Sublobes

PRPM soils of the Ontonagon, Keweenaw Bay, and Michigamme sublobes occur in northwestern portions of the upper peninsula of MI (MLRAs 90A, 93B, 94B) (Figure 3.5). These glacial deposits correlate to the deposition of glacial materials bound to the extent of the Woodfordian moraines in northern MI (Figure 3.7, C). Like the soils of the Superior sublobes in northern WI (Chippewa, Wisconsin Valley, Langlade Lobes), PRPM soils occur on a variety of glacial landforms (moraines, outwash plains, drumlins, etc.) throughout the area. PRPM soils on the moraines are characterized as poorly sorted (gravelly to cobbly), loamy-to-sandy till deposits (e.g. Keweenaw, Montreal, Pemene and similar soils). Compared to the moraines of the other Superior sublobe deposits in northwestern WI, tills of the moraines deposited by the Ontonogan, Keweenaw Bay, and Michigamme sublobes in MI tend to be like those in northeastern WI (sandier in texture and are more podzolized). The majority of these tills are also blanketed by a thin brown “mantle” of other materials (loess, lake sediments, etc.) not considered to be problematic RPM, but contain a dense, root restricting and water perching layer known as a fragipan in the subsurface (e.g. Gogebic, Munising, Trimountain, Skanee, Wakefield, and similar soils). Some tills are also recognized in more depressional, low-lying areas with poorer drainage within larger moraines and till plains (e.g. Gay, Gratiot, and similar soils).

In addition, PRPM soils derived from outwash and glaciofluvial deposits of these sublobes are very sandy, stratified, high in rock fragments (as gravels, cobbles, etc.), and occur on outwash plains, valley trains, and ice-contact stratified drift landforms (kames, eskers, etc.) in the landscape (e.g. Annalake, Karlin, Manitowish, Waiska, and similar soils). Many of these sandy deposits also underlain by loamy tills, and occur on ground and end moraines (e.g. Escanaba, Lac La Belle, Yalmer, and similar soils).

Furthermore, in northwestern most parts of the upper peninsula of MI (MLRA 93B – including Isle Royale), glacial tills are typically moderately deep-to-shallow to bedrock like that of RPM soils of easternmost areas of MLRA 93A in MN. These soils are characterized as poorly sorted (gravelly, cobbly, stony), loamy tills underlain by non-problematic igneous, metamorphic and/or conglomerate bedrock found on rocky knolls, benches, and bedrock-controlled moraines and till plains (e.g. Arcadian, Chippewa Harbor, Nipissing, Peshekee, and similar soils). Like the tills in MLRA 90A and more southern areas in MLRA 93B, these PRPM soils are sometimes blanketed by browner loamy mantles of other materials (eolian deposits, alluvium, etc.) that are not problematic RPM (e.g. Michigamme, Peshekee, and similar soils).

Finally, some lake deposits are recognized in some areas. These PRPM soils are siltier in texture, stratified, and/or have evidence of wave action (e.g. Fence, Gaastra, Paavola, and similar soils). Towards the eastern parts of the area (east of the Michigammi sublobe), PRPM soils are primarily recognized as proglacial lake deposits on lake plains with very fine silty and clayey textures that contain no rock fragment (e.g. Froberg, Ontonagon, Rudyard, Shag, Spear, and similar soils). Many of these PRPM soils also occur in eastern parts of the upper peninsula of MI and northern parts of the lower peninsula of MI (MLRAs 94A, 94B, 94C) (see "*Michigan Basin*" section of this chapter for more information).

Proglacial Lake Aitkin and Upham

PRPM soils derived from and/or associated with proglacial lake sediments of Lake Aitkin and Upham occur in east-central MN (MLRA 88) (Figure 3.5). PRPM soils in this area predominantly occur on lake-washed till plains, drumlins, and moraines. The underlying material on these landforms is problematic, dark-red, loamy to clayey glacial till (similar to tills of the Mille-Lacs moraine complex) and lake sediments. These lacustrine materials and tills are derived from proglacial lake sediments from Lake Upham and Aikin and materials reworked by the St. Louis sublobe that advanced into central MN, respectively (Figure 3.11).[55] In MLRA 88, these soils are commonly blanketed with a "mantle" of browner, loamy materials (loess, eolian sediments, water sorted deposits, and glaciofluvial deposits) that are not recognized as problematic RPM, however, it is possible for problematic RPM to

[55] The St. Louis sublobe is part of the Des Moise Lobe (Figure 3.6). The advance of this sublobe occurred during the same time the larger Des Moines Lobe advanced to cover southern MN towards the end of the Wisconsinan glaciation (Bray, 1977; Lusardi, 1997).

occur in these areas from the underlying till material.[56] Soils representative of tills overlain by loess and/or fine-textured eolian sediments are the Hibbing, Fayal, McQuade, Mooseline, and similar soils. PRPM soils representative of tills overlain by sandy, stratified glaciofluvial materials are the Hellwig, Majestic, Turpela and similar soils. Soil representative of tills overlain by water sorted deposits are the Schisler and similar soils. Finally, some problematic glacial tills are also overlain by organic materials (i.e. histic epipedons) in lower-lying areas on drumlins, moraines, and till plains. These are represented by the Baden, Blackhoof, and similar soils.

Superior Lobe Alluvium

PRPM soils associated with the Superior Lobe and its sublobes are also recognized as recent alluvial deposits overlying the glacial deposits that characterize the Great Lakes region.[57] Characteristics of these recent alluvial deposits are similar to that of outwash and glaciofluvial deposits (sandy, high rock fragment content, stratification), however, sands tend to be finer in grain size (very fine to fine sand textures), and the soils occur in floodplain, bottomland, and low-lying stream terrace positions in association with active stream and rivers systems in the landscape. Alluvial soils representative of the Mille Lacs-Wright-Cromwell-Highland moraine complex are the Scott Lake, Rosholt, and similar soils. Alluvial soils representative of the Superior Lake Plain area are the Dechamps, Gull Point, Moquah, and similar soils. Alluvial soils representative of the Superior sublobes in both northern WI and

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[56] Areas in USDA-NRCS MLRA 88 were largely not included in RPM guidance maps for the Great Lakes region (Figure 3.5) following comment provided by USDA-NRCS project collaborators, however, areas within this MLRA may possibly contain problematic RPM at depth. Soil series that can be derived from problematic RPM mentioned in this section's "user notes" are included in Table 3.12.

[57] These alluvial deposits are recognized in RPM guidance maps as they drain and/or transport problematic RPM deposited by the Superior lobe and its sublobes throughout the sub-region (Figure 3.5).

the western areas of the upper peninsula of MI are the Arnhein, Pelkie, Sturgeon and similar soils. Lastly, many alluvial soils in MLRA 91B occur in association with outwash and glaciofluvial deposits along the border of MN and WI (e.g. Bigisland, Clemens, Dairyland, Makwa, Rockmarsh, and similar soils). Alluvium derived from problematic RPM of the Superior Lobe may also be possible in parts of MLRA 91A slightly west of the Mille-Lacs moraine complex and St. Croix moraines in central MN, but deposits here tend to be browner in color.

The Kewaunee Formation: Green Bay and Lake Michigan Lobes

Problematic RPM of this group in the Great Lakes region are derived from red- colored, late Wisconsinan-aged, glacial materials of the Kewaunee formation deposited in association with the Green Bay and Lake Michigan Lobes that once covered eastern WI adjacent to Lake Michigan at the height of the Wisconsian glaciation (Figures 3.5, 3.10). Like the Superior Lobe, the Green Bay and Lake Michigan Lobes advanced as one broad glacier welded to other lobate fronts of ice over the region, and separated into distinct lobes of ice during glacial retreat towards the end of the Pleistocene (Lusardi, 1997). Pre-Wisconsinan glaciations (Nebraskan, Kansan, Illinoian) also occurred in this RPM area during the Pleistocene, however, little evidence of the older glacial deposits remain at the soil surface (Syverson and Colgan, 2004; USDA-NRCS, 2006). The bedrock underlying much of these glacial materials are Cambrian-aged sandstones, and Ordovician-to-Silurian-aged dolomite and limestone sequences separated by thinner layers of sandstones and shales (Wisconsin Geological and Natural History Survey, 2006). These Cambrian sandstones were laid down as wave-eroded, shoreline and river sediments as the region became submerged by a shallow sea multiple times during the early Paleozoic (Wisconsin Geological and Natural History Survey, 2006). Likewise, the Silurian and Ordovician limestones and dolomites were originally deposited as reefs of calcium carbonate in offshore marine-environments under a warm, tropical climate (Wisconsin Geological and Natural History Survey, 2006). This bedrock occurs on the fringes of the older, exposed igneous, metamorphic, etc. rocks of the Canadian shield to the north and east, and is not recognized as problematic RPM.

Regarding the Kewaunee formation, however, this formation consists of dark-red, calcareous, fine-to-medium textured diamicton units of a (glacio)lacustrine origin similar to tills and lake sediments characteristic of the Superior Lake Plain and Miller Creek formation in MN and northern WI (Petersen et al., 1967; Peterson, 1982; Syverson and Colgan, 2004; Syverson et al., 2011, see *"Superior Lobe"* section prior) (Figure 3.10, 3.12). These red tills and lacustrine sediments are believed to be deposited during ice retreat of the Superior, Green Bay, and Lake Michigan lobate fronts in the late-Wisconsinan where meltwaters from several proglacial lakes (containing the red sediments) in the region were siphoned into the Lake Michigan basin and the Green Bay Lowlands (~13 Kya) (Petersen et al., 1967; Syverson and Colgan, 2004). The source of these red glacial materials is correlated to the red, sedimentary sequences of the Superior Basin originally deposited in the Precambrian (~1880 Mya) (Petersen et al., 1967; Syverson and Colgan, 2004) (see "*Superior Lobe"* section prior*)*. Later re-advancements of the Green Bay and Lake Michigan Lobes transported these lake sediments to surrounding uplands and deposited them as glacial till as far south as Milwaukee along the Lake Michigan shoreline (Petersen et al., 1967; Rovey II and Borucki, 1995; Syverson and Colgan, 2004; Colgan, 1999). Some tills of the younger Holy Hill formation[58] are sometimes redder in color and calcareous like the problematic tills of the Kewaunee formation (Syverson et al., 2011, see “Horicon” and “Liberty Grove” members). Thus, the Holy Hill formation was also included in RPM guidance maps for the Great Lakes region (Figure 3.5, 3.10).

The distribution of problematic RPM and their associated soils of the Kewaunee formation are shown in RPM guidance maps for the Great Lakes region (Figure 3.5). Table 3.13 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Kewaunee formation.

Table 3.13. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Kewaunee Formation.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	K – Northern Lake States Forest and Forage Region	89 – Wisconsin Central Sands 90A – Wisconsin and Minnesota Thin Loess and Till, Northern Part 94B – Michigan Eastern Upper Peninsula Sandy Drift 95A – Northeastern Wisconsin Drift Plain 95B –Southern Wisconsin and Northern Illinois Drift Plain

Table 3.14 lists the soil series and geological formations identified as potential problematic RPM (included in RPM guidance maps) that are associated with the Kewaunee formation.

[58] The Holy Hill formation is composed of glacial materials deposited during the late-Wisconsinan glaciation and is primarily associated advancement and retreat of the Green Bay Lobe. This formation is composed mostly of sandy glacial till that is characteristically yellowish-brown to brown in color (Syverson et al., 2011) (Figure 3.10).

Table 3.14. Geological formations and soil series identified as potential problematic RPM that are associated with the Kewaunee formation.

Geological Formation(s)	Soil Series		
Bayfield Group	Angelica	Moquah	Tipler
Chequamegon Sandstone	Banat	Mosel	Wabeno
Devil's Island Sandstone	Bonduel	Moshawquit	Waymor
Orienta Sandstone	Borth	Nadeau	Winneconne
Fond du Lac Formation	Briggsville	Omena	Worchester
Green Bay Lobe Till	Cress	Omro	Wormet
Hinckley Sandstone	Cunard	Onaway	Wyocena
Holy Hill Formation*	Elderon	Oshkosh	Zittau
Horicon Member*	Emmert	Ossineke	Zurich
Liberty Grove Member*	Escanaba	Pearl	
Kewaunee Formation*	Fairport	Pecore	
Branch River Member*	Fence	Peebles	
Chilton Member*	Frechette	Pelkie	
Florence Member*	Gaastra	Pemene	
Glenmore Member*	Hortonville	Perote	
Kirby Lake Member*	Kaukauna	Peshekee	
Middle Inlet Member*	Kennan	Peshtigo	
Ozaukee Member*	Keshena	Poy	
Silver Cliff Member*	Kewaunee	Poygan	
Two Rivers Member*	Keweenaw	Rabe	
Valders Member*	Kiva	Richford	
Jacobsville Formation	Kolberg	Rosholt	
Jacobsville Sandstone	Longrie	Shawano	
Oronto Group	Manawa	Solona	
Copper Head Conglomerate	Manistee	Stambaugh	
Freda Sandstone	Mecan	Symco	
Nonesuch Shale	Montello	Tilleda	

**Note – Geological formations indicated with an "*" are surficial formations given to names of the Wisconsinan-aged tills mapped primarily in northern WI (not formations pertaining to underlying bedrock) (Syverson and Colgan, 2004) (Figure 3.10). Bedrock formations are the same as those in the Superior Basin responsible for the occurrence of problematic RPM associated with the Superior Lobe discussed previously.*

The Kewaunee Formation: F21 – Red Parent Material User Notes

PRPM soils derived from the Kewaunee formation, deposited in association with the Green Bay and Lake Michigan Lobes, occur on a variety of glacial landforms throughout the area. Poorly-sorted (gravelly, cobbly, etc.), fine-loamy and coarse-loamy glacial tills are characteristic of PRPM soils on till plains, drumlins, and moraines (ground, end, etc.). Fine-loamy tills occur more to the east (MLRA 95A) (e.g. Angelica, Hortonville, Keshena, Ossineke, Poygan, and similar soils). Coarse-loamy tills occur more to the southwest (MLRA 95B) and northern areas near deposits of the Superior sublobes in the upper peninsula of MI (e.g. Frechette, Keweenaw, Mecan, Pemene, Wyocena, and similar soils). Some tills are mixed with both fine- and coarse-loamy materials on outwash-veneered moraines (e.g. Omro, Onaway, Rabe, and similar soils). Many tills are also underlain by sandier, outwash-type deposits that can also be RPM (e.g. Banat, Kiva, Nadeau, Pecore, and similar soils), while others are sometimes capped by a browner, loamy "mantle" of material (loess, eolian sands, etc.) that is not problematic RPM (e.g. Kennan, Kewaunee, Manawa, Waymor, and similar soils). It is common for rock fragments (gravels, cobbles, etc.) within the tills to be dolomitic, sourced from the underlying bedrock of the region. Lastly, many of the glacial tills derived from the Kewaunee formation are also underlain by white- to gray-colored limestone and/or dolomite bedrock that is not problematic RPM (e.g. Bonduel, Cunard, Fairport, Kolberg, Longrie, and similar soils) on bedrock-controlled moraines, drumlins, and till plains.

PRPM soils that occur on outwash plains and other (glacio)fluvial drift landforms (kames, eskers, etc.) derived from the Kewaunee formation are typically coarse-textured (i.e. coarse sands), skeletal (extremely gravelly, cobbly, etc.), and stratified (e.g. Elderon, Emmert, Gaastra, Mecan, Shawano, and similar soils). These mostly occur more in western areas worked by the Green Bay Lobe towards/within MLRAs 89, 90A, 95B, and areas also associated with the Holy Hill formation (Figure 3.10). Like the glacial tills on moraines, some of these outwash and (glacio)fluvial deposits are capped by a loamy, browner "mantle" of material (loess, water-laid sediments, etc..) that is not problematic RPM (e.g. Stambaugh, Wabeno, Wormet, Zurich, and similar soils). Alluvial soils reworked by streams and rivers of the local watersheds are closely related to these outwash-type deposits in similar areas, but occur on active floodplains, stream terraces, and drainageways in the landscape (e.g. Cress, Moquah, Pelkie, Rosholt, Tipler, Worchester, and similar soils).

Furthermore, a variety of lacustrine deposits are recognized. These lacustrine sediments occur primarily on flat, low-lying glacial lake basins between/within moraines and till plains, and range from very clayey in texture to fine-sand- and silt-stratified deposits (e.g. Briggsville, Fence, Kaukauna, Montello, Winneconne, and similar soils). Many lake sediments are commonly capped by browner, loamy "mantles" that are not problematic RPM (e.g. Oshkosh), while others are commonly overlain and/or underlain by sandier, gravelly outwash deposits (e.g. Borth, Mosel, Poy, Zittau, and similar soils).

Finally, amongst all of the soils on these landforms and deposits of the Kewaunee formation, many of them are calcareous and/or have carbonate nodules in the subsurface sourced from the underlying calcareous bedrock (e.g. Omena, Oshkosh, Pecore, Peshtigo, Symco, and similar soils). Many of these calcareous soils have characteristics of prairie soils (dark, organic-rich epipedons) that may mask red colors in surface horizons characteristic of problematic RPM (e.g. Montello, Peebles, Poy, Poygan, Winneconne, and similar soils). Other Field Indicators may be more useful in delineating hydric soils in these instances, however, these soils were included in RPM guidance maps for the Great Lakes region not to miss potential problematic RPM that may occur in the region.

The Michigan Basin

Problematic RPM of this group in the Great Lakes RPM region belongs to a collection of red-colored, Wisconsinan-aged glacial deposits (predominantly of lacustrine origin) found throughout the east upper and north lower peninsulas of MI (Figure 3.5). Unlike the other groups of problematic RPM discussed in the Great Lakes, the deposits in these areas occur within the Michigan Basin, a nearly circular pattern of sedimentary strata that dips downward uniformly towards the center of the lower peninsula (Gillespie et al., 2008) (Figure 3.13).

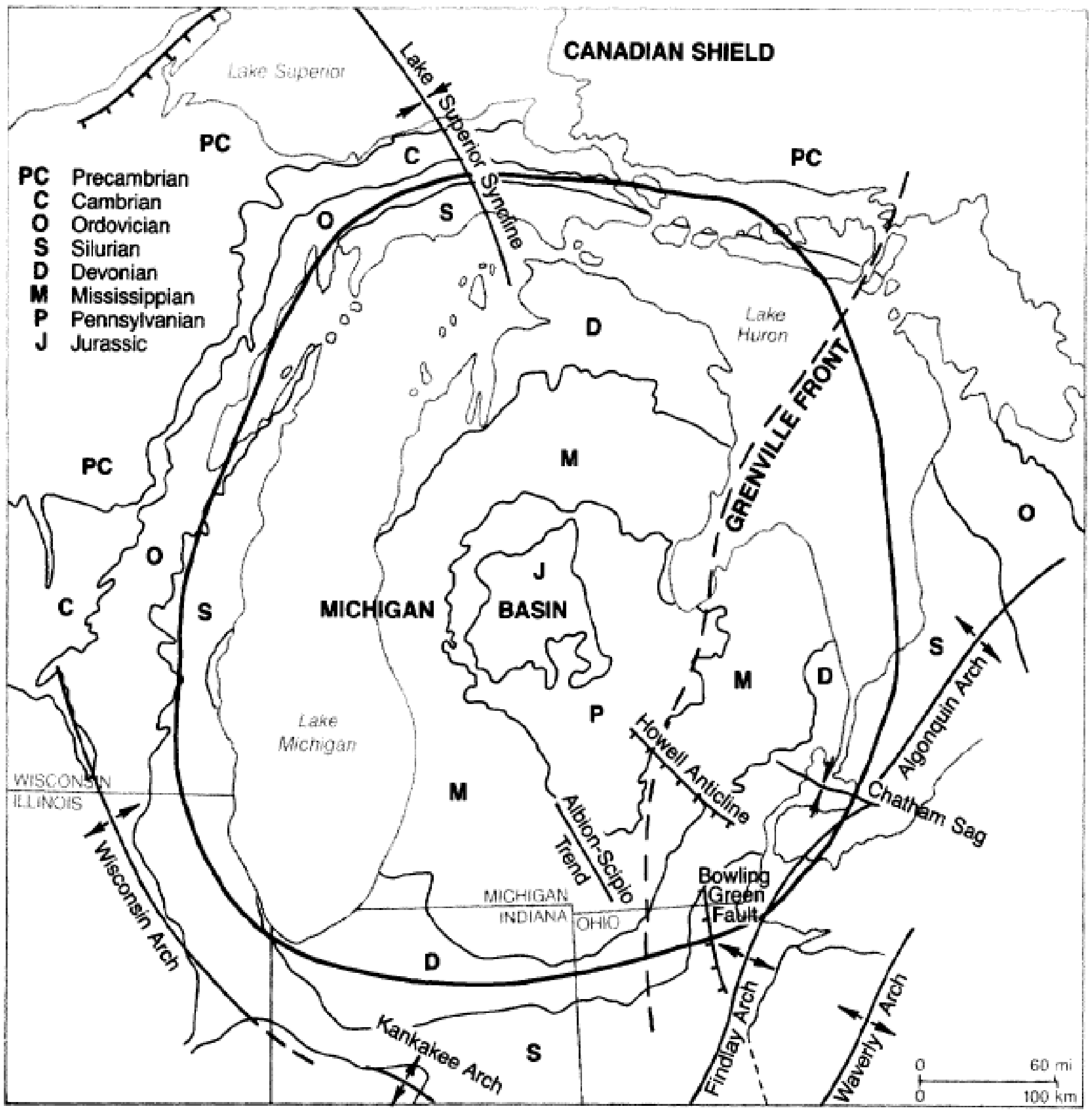

Figure 3.13. *Location and structural trends of the Michigan Basin. The approximate limits of the basin are shown by the heavy solid line. Figure 30-1 from Catacosinos et al. (1990).*

The sedimentary strata subcrop in a series of irregular concentric rings and range in age from Cambrian at the margins of the basin to Pennsylvanian (capped by a small area of Jurassic) in the center (Cohee, 1965; Michigan Geological Survey, 2005; Gillespie et al., 2008) (Figure 3.13). Overall, the rocks of the basin are dominated mostly by dolomite and limestone sequences, some siliclastics (shales, sandstones, etc.), and evaporites (gypsum, halite) deposited as the region was repeatedly submerged and un-submerged by a shallow sea throughout the Paleozoic (Cohee, 1965; Gillespie et al., 2008). The east upper peninsula of MI is underlain by older Paleozoic rocks (Cambrian to Silurian) and the north lower peninsula is underlain by younger Paleozoic rocks (Silurian to Pennsylvanian). No rocks younger than the Jurassic beds in the center of basin remain in the state (Cohee, 1965; Gillespie et al., 2008).

Furthermore, the glacial history of the Michigan Basin where problematic RPM has been identified is quite complex. The relatively weak and soft sedimentary rocks (eroded and down-cut by subaerial processes before the Pleistocene glaciations) allowed for three major lobes of the Laurentide Ice Sheet (i.e. Lake Michigan, Saginaw, and Huron-Erie) to advance from the north and deepen and widen the basin over the last 2 Mya (Figure 3.14) (Gillespie et al., 2008).[59]

[59] This Michigan Basin was glaciated multiple times during the Pleistocene (i.e the Nebraskan, Kansan, Illinoian glacial periods) like the other areas of the Great Lakes region discussed previously; however, there is little evidence that dates glacial deposits younger than early Wisconsinan at the surface (Schaetzl, 2001; Eschman and Mickelson, 1986; Guzman, 2014; USDA-NRCS, 2006).

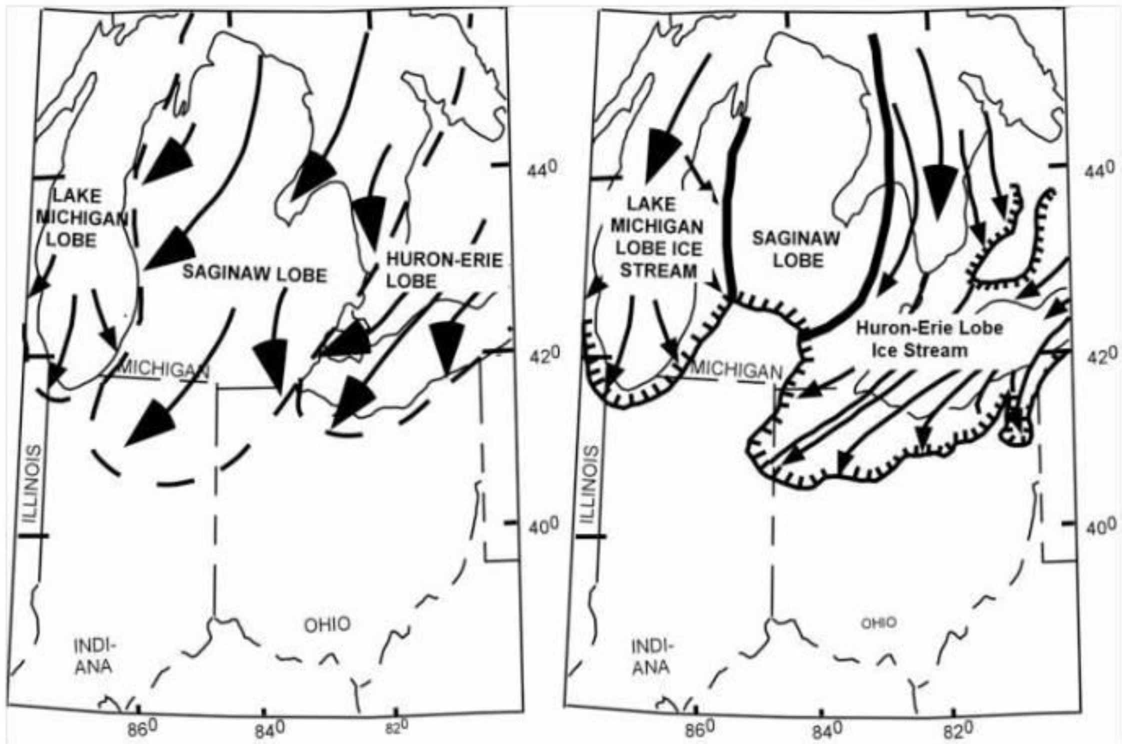

Figure 3.14. *Lake Michigan, Saginaw, and Huron-Erie Lobes in the Great Lakes region. Advancement of the Saginaw Lobe after ~21 Kya (left) and retreat of the Saginaw Lobe ~16-15 Kya (right). The advancement of the Saginaw Lobe cut into soft, sedimentary bedrock to form the Michigan Basin. Figure 10 from Kehew et al. (2005).*

Generally, the Lake Michigan Lobe advanced across western MI and small parts of eastern WI from the north-northwest, its greatest extent reached southward beyond Chicago, IL (Kehew et al., 2005). The Huron-Erie Lobe advanced across eastern MI from the northeast through a series of valleys later sculpted into basins now filled by Lake Huron and Lake Erie (Dreimanis and Goldthwait, 1973; Larson and Schaetzl, 2001). And finally, the Saginaw Lobe pushed out as an extension of the Huron-Erie Lobe into the central areas of the lower peninsula of MI from the northeast (i.e. Saginaw Bay) (Kehew et al., 2012; Guzman, 2014).

Like the other lobes in the Great Lakes region, these fronts were welded together as one mass of ice and only began to separate in distinct tongues towards the end of the Wisconsinan glaciation (Lusardi, 1997; Gillespie et al., 2008). It is generally understood that the Saginaw Lobe was a thinner, cleaner (i.e. contained less glacial debris) mass of ice compared to the other lobes, and therefore, advanced and retreated more rapidly and irregularly into central parts of the lower peninsula of the state than did the other lobes in the region (Kehew et al., 2012; Schaetzl, 2001) (Figure 3.14, right). The east upper peninsula of MI was locked under ice (at the junction of the different lobate fronts that radiated out from the north across the region) until the ice finally retreated towards Canada at the end of the glacial period. As previously discussed, problematic RPM in the west upper peninsula of MI owes its characteristics and deposition to glacigenic and glaciolacustrine processes directed from the Superior and Green Bay Lobes within the structural boundaries of the Superior Basin and Canadian Shield.

Towards the end of the Wisconsinan glaciation, proglacial lakes that eventually formed into the current Great Lakes from melting ice attribute much to the glacial geology of the area. While the overall area experienced flooding from numerous proglacial lakes as ice melted, one of the most significant in the region was proglacial Lake Algonquin that joined meltwaters from the Superior Lobe (mostly its sublobes in northern WI and MI) in the west and meltwaters from the Lake Michigan and Saginaw Lobes in the east (Farrand, 1988; Gillespie et al., 2008).[60] This large proglacial lake was ultimately formed following the meltout of ice from the Superior fronts, and flooded the entire area of the east upper peninsula of MI and northern parts of the lower peninsula of MI (only some small islands of higher elevation

[60] The Lake Michigan, Saginaw, and Huron-Erie lobes retreated north to Canada from the Great Lakes region earlier than did ice of the Superior Lobe and its sublobes in the northwest. Glacial retreat of the lobate fronts in MI occurred ~16-15 Kya (Kehew et al., 2012; Kehew et al., 2005), while ice of the Superior fronts is dated to have melted back from the region ~13-12 Kya (Bray, 1977).

remained above the waters) (Gillespie et al., 2008; Larson and Schaetzl, 2001; Farrand, 1988). Eventually, a combination of factors such as drainage, isostatic rebound, climate change, etc. resulted in the current configuration of the Great Lake water bodies we see today.[61]

From this extensive geological history, several source rocks are possible for the problematic RPM ultimately deposited as glacial tills and lake sediments in the east upper and north lower peninsulas of MI (Figure 3.5). The most probable source are the red, sedimentary rocks of the Superior Basin (see *"Superior Lobe"* section prior) where red sediments from this basin may have been transported and deposited by ice of the Saginaw Lobe and/or by meltwaters from proglacial lakes (Lake Algonquin) during later phases of the Wisconsinan glaciation. Some outcrops of the Jacobsville Formation/Sandstone, a characteristic red, siliclastic rock of the Superior Basin (Baumann, 2010), also occur in the east upper peninsula along the border of Lake Superior (Michigan Geological Survey, 2005).

Another possible source for problematic RPM in MI, however, are Ordovician- and Silurian-aged bedrock formations found within the Michigan Basin on the upper peninsula, such as the Queenston formation and Salina Group, that are known to contain red, sedimentary, hematite-rich shales (Brogly et al., 1998; Sonnenfeld and Al-Aasm, 1991). These rocks were laid down in fluvial and deltaic environments as the overall region transgressed from a marine environment submerged by shallow seas to a terrestrial environment under a warm, tropical

[61] For more information and discussion on the proglacial lakes that formed the current Great Lakes, see Leverett (1929); Farrand (1960); Huber (1973); Farrand (1988) and Larson and Schaetzl (2001), amongst others.

climate in the Paleozoic (Brogly et al., 1998; Sonnenfeld and Al-Aasm, 1991).[62] These bedrock formations on the upper peninsula have not been confirmed as the source of problematic RPM in these areas (via CCPI analyses and comment by project collaborators like the rocks of the Superior Basin); thus, they were not included in RPM guidance maps for the Great Lakes region (Figure 3.5).

The final possible source of problematic RPM to produce the red glacial tills and lake deposits in MI are the Jurassic-aged red bed formations that occur within the center of the Michigan Basin on the lower peninsula (Figure 3.13). Red materials from these beds may have been transported and deposited by lobate fronts of ice (particularly the Saginaw Lobe) throughout the north lower peninsula of MI as the ice advanced and retreated over the region (Figure 3.14). These source rocks of problematic RPM in these areas is more unlikely, however, as the Jurassic red beds are understood to be very poorly preserved or buried deep beneath tills dated from Pre-Wisconsinan glaciations in the subsurface (Fowler and Kuenzi, 1978; Cross, 1998; Gillespie et al., 2008). For these reasons, these sedimentary red beds were not included in RPM guidance maps for the Great Lakes region (Figure 3.5). It should also be noted that the bulk of RPM mapped in the east upper and north lower peninsulas of MI are PRPM soils mapped in the other soil and parent material groups for the Great Lakes region (i.e. Superior Lobe, Kewaunee Formation, see Tables 3.12 and 3.14). Very few soil samples and comments were received from project

[62] The Queenston Formation and Salina Group also occur in the Ontario-Erie and Finger Lakes area in this study's "Northeast and Mid-Atlantic" region (see "*Ontario-Erie Plain and Finger Lakes*" in this chapter's "*Northeast and Mid-Atlantic*" section discussed previously). Compared to the Ontario-Erie Plain and Finger Lakes region, the Queenston Formation and Salina Group in the Michigan Basin are poorly understood (Brogly et al., 1998; Sattler, 2015).

collaborators in these areas mapped in MI for the Great Lakes region and additional data may aid in further constraining the extent of problematic RPM in these areas.

The distribution of problematic RPM and their associated soils of the Michigan Basin are shown in RPM guidance maps for the Great Lakes region (Figure 3.5). Table 3.15 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Michigan Basin.

Table 3.15. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Michigan Basin.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Northcentral and Northeast	K – Northern Lake States Forest and Forage Region	94A – Northern Michigan and Wisconsin Sandy Drift* 94B – Michigan Eastern Upper Peninsula Sandy Drift 94C – Michigan Northern Lower Peninsula Sandy Drift*
	L – Lake States Fruit, Truck Crop, and Dairy Region	96 – Western Michigan Fruit Belt* 98 – Southern Michigan and Northern Indiana Drift Plain* 99 – Erie-Huron Lake Plain*

**Note – no soil samples were received and/or analyzed for CCPI from these MLRAs. RPM mapped in the east upper and north lower peninsulas of MI for the Great Lakes Region (Figure 3.5) are mostly mapped based on the same soil series found in other areas of the Great Lakes Region (Superior Lobe, Kewaunee Formation, etc.). No comment was provided to remove these areas mapped as RPM in MI when draft maps were open for public comment in the early winter of 2017.*

Table 3.16 lists the soil series and geological formations identified as potential problematic RPM (included in RPM guidance maps) that are associated with the Michigan Basin.

Table 3.16. Geological formations and soil series identified as potential problematic RPM that are associated with the Michigan Basin.

Geological Formation(s)	Soil Series	
Bayfield Group	Algonquin	Morganlake
Chequamegon Sandstone	Allendale	Nadeau
Devil's Island Sandstone	Angelica	Negwegon
Orienta Sandstone	Annalake	Nunica
Fond du Lac Formation	Bergland	Ocqueoc
Hinckley Sandstone	Biscuit	Oldman
Ionia Formation†	Bonduel	Omena
Jacobsville Formation	Cunard	Onaway
Jacobsville Sandstone	Engadine	Ontonagon
Jurassic Red Beds†	Fairport	Ossineke
Oronto Group	Fence	Pelkie
Copper Head Conglomerate	Fibre	Pickford
Freda Sandstone	Gaastra	Poy
Nonesuch Shale	Gay	Rudyard
Queenston Formation†	Graveraet	Solona
Salina Group†	Karlin	Sporley
	Kellogg	Springport
	Kiva	Superior
	Longrie	Waiska
	Manistee	

Note - Bedrock formations are the same as those in the Superior Basin responsible for the occurrence of problematic RPM with the Superior and Kewaunee Formation discussed previously. Formations indicated with a "†" were included as possible source rocks for problematic RPM, however, these formations have not been confirmed as problematic RPM with CCPI analyses or comment by project collaborators, and therefore, were not included in RPM guidance maps for the Great Lakes region (Figure 3.5). Soil series in these east upper and north lower peninsulas of MI are mapped from the same soil series found in other areas of the Great Lakes region (i.e. Superior Lobe, Kewaunee Formation, etc.) (see Tables 3.12 and 3.14). No comment was provided to remove these areas mapped as problematic RPM in MI when draft maps were open for public comment in the early winter of 2017.*

The Michigan Basin: F21 – Red Parent Material User Notes

Like the PRPM soils of the other soil and parent material groups in the Great Lakes region, PRPM soils on the east upper and north lower peninsulas of MI occur in a wide variety of glacial deposits. Most of the soils in these areas, however, are of a (glacio)lacustrine origin, have materials derived from lake deposits within the overall soil profile, and/or are closely associated with lacustrine landforms. PRPM soils derived completely from lacustrine sediments are dark-red, calcareous, loamy, silty or clayey, and occur on lake plains, basins, and terraces (e.g. Algonquin, Biscuit, Engadine, Negwegon, Nunica, Ontonagon, Pickford, Rudyard, and similar soils). Some lacustrine deposits are overlain by a sandy to loamy, poorly sorted (gravelly, cobbly, etc.) mantle of glacial till, or a sandy, stratified mantle of outwash/glaciofluvial sediments on lake basins, lake terraces, lake plains, lake-washed outwash plains and moraines (e.g. Allendale, Kellogg, Manistee, and similar soils). These overlying till and glaciofluvial deposits can both be browner or redder in color, but the underlying lacustrine sediment is typically dark-red in color characteristic of problematic RPM.

Furthermore, some red-colored glacial tills not associated with lacustrine landforms are recognized on moraines (ground, end, etc.) and drumlins in the area (e.g. Angelica, Graveraet, Oldman, Onaway, Ossineke and similar soils). Some tills in depressional areas within larger moraines are also recognized (e.g. Gay and similar soils), and can contain dark, organic-rich surface horizons typical of prairie soils that can mask the red color of problematic RPM (e.g. Solona and similar soils). Red tills overlying the calcareous bedrock of the region also occur on some isolated, bedrock-controlled uplands (e.g. Bonduel, Cunard, Fairport, Longrie and similar soils). Very few outwash and/or glaciofluvial soils are recognized, but those that are have sandy textures, high stratification, and are typically skeletal (extremely gravelly, cobbly, etc.) (e.g. Karlin, Morganlake, Waiska and similar soils). Some alluvium derived from problematic RPM is also recognized, but occurs in active floodplain and stream terrace parts of the landscape (e.g. Pelkie and similar soils). Again, it should be noted that these soils are also mapped in the other major areas where problematic RPM occurs throughout the Great Lakes region (i.e. Superior Lobe, Kewaunee Formation, see Tables 3.12 and 3.14), and additional data may aid in further constraining the extent of problematic RPM in these areas.

South-Central Region

A total of 300 soil samples from 148 sites (~32% of the total 456 sites) were submitted and analyzed for CCPI from the South-Central region. Of these, 302 samples (114 sites) were provided from KSSL archives, 56 samples (21 sites) from USDA-NRCS soil scientists, and 24 samples (13 sites) from USACE field personnel. From these samples, problematic RPM has been identified for appropriate use of the F21 – Red Parent Material indicator in twenty-eight USDA-MLRAs of eight major LRRs. These are mostly contained within the USACE Great Plains and Atlantic and Gulf Coast Plain Regional Supplement Regions, with minor areas also occurring in the Midwest and the Eastern Mountains and Piedmont Regions. An additional fifteen USDA-NRCS MLRAs of two additional LRRs may also contain problematic RPM for use of the F21 – Red Parent Material field indicator in western portions of this South-Central region (some of which occurring in the USACE Western Mountains, Valleys and Coast Regional Supplement Region), however, no soil samples were available to conduct CCPI analyses and are needed to confirm the occurrence of problematic RPM in these areas (Table 3.17).

Table 3.17. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas within this study's South-Central region where application of the F21 - Red Parent Material indicator is appropriate.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Western Mountains, Valleys, & Coast*	E – Rocky Mountain Range and Forest Region*	48A – Southern Rocky Mountains* 48B – Southern Rocky Mountain Parks* 49 – Southern Rocky Mountain Foothills*
Great Plains	G – Western Great Plains and Irrigated Region*	67B – Central High Plains, Southern Part* 69 –Upper Arkansas Valley Rolling Plains* 70A – Canadian River Plains and Valleys* 70B – Upper Pecos River Valley*
	H – Central Great Plains Winter Wheat and Range Region	72 – Central Highland Table* 73 – Rolling Plains and Breaks* 74 – Central Kansas Sandstone Hills* 76 – Bluestem Hills* 77A – Southern High Plains, Northern Part* 77B – Southern High Plains, Northwestern Part* 77E – Southern High Plains, Breaks* 78A – Rolling Limestone Prairie 78B – Central Rolling Red Plains, Western Part 78C – Central Rolling Red Plains, Eastern Part 79 – Great Bend Sand Plains* 80A – Central Rolling Red Prairies 80B - Texas North-Central Prairies
	I – Southwest Plateaus and Plains Range and Cotton Region	81B – Edwards Plateau, Central Part 81C – Edwards Plateau, Eastern Part 82A – Texas Central Basin
	J – Southwestern Prairies Cotton and Forage Region	82B – Wichita Mountains+ 84A – North Cross Timbers+ 84B – West Cross Timbers 84C – East Cross Timbers 85 – Grand Prairie 86A – Texas Blackland Prairie, Northern Part 86B – Texas Blackland Prairie, Southern Part 87A – Texas Claypan Area, Southern Part 87B – Texas Claypan Area, Northern Part
Midwest	M – Central Feed Grains and Livestock Region	112 – Cherokee Prairies
Eastern Mountains and Piedmont	N – East and Central Farming and Forest Region	118A – Arkansas Valley and Ridges, Eastern Part 118B – Arkansas Valley and Ridges, Western Part
Atlantic and Gulf Coast Plain	O – Mississippi Delta Cotton and Feed Grains Region	131A – Southern Mississippi River Alluvium 131B – Arkansas River Alluvium 131C – Red River Alluvium
	P – South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	133B – Western Coastal Plain 134 – Southern Mississippi Valley Loess 135B – Cretaceous Western Coastal Plain
	T – Atlantic and Gulf Coast Lowland Forest and Crop Region	150A - Gulf Coast Prairies 150B – Gulf Coast Saline Prairies

**Note – USACE Regional Supplement Regions and USDA-NRCS LRRs, and MLRAs indicated with a "*" are the fifteen additional MLRAs where no data collection/CCPI analyses was available to confirm the occurrence and distribution of problematic RPM in these areas. See "Central Red Bed Plains Alluvium," "Central Red Bed Plains Alluvium: Arkansas and Red Rivers" sections for guidance on the potential use of the F21 – Red Parent Material field indicator in these areas. For USDA-NRCS MLRAs indicated with a (+), see "Central Red Bed Plains" and User notes sections for guidance on the potential use of the F21 – Red Parent Material field indicator in these areas. Some USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs indicated with a "*" are also further discussed in the Desert Southwest and Western Mountains section of this chapter.*

A guidance map for the potential occurrence of problematic RPM, and therefore the appropriate application of field indicator F21 – Red Parent Material, in the South-Central region is shown in Figure 3.15.

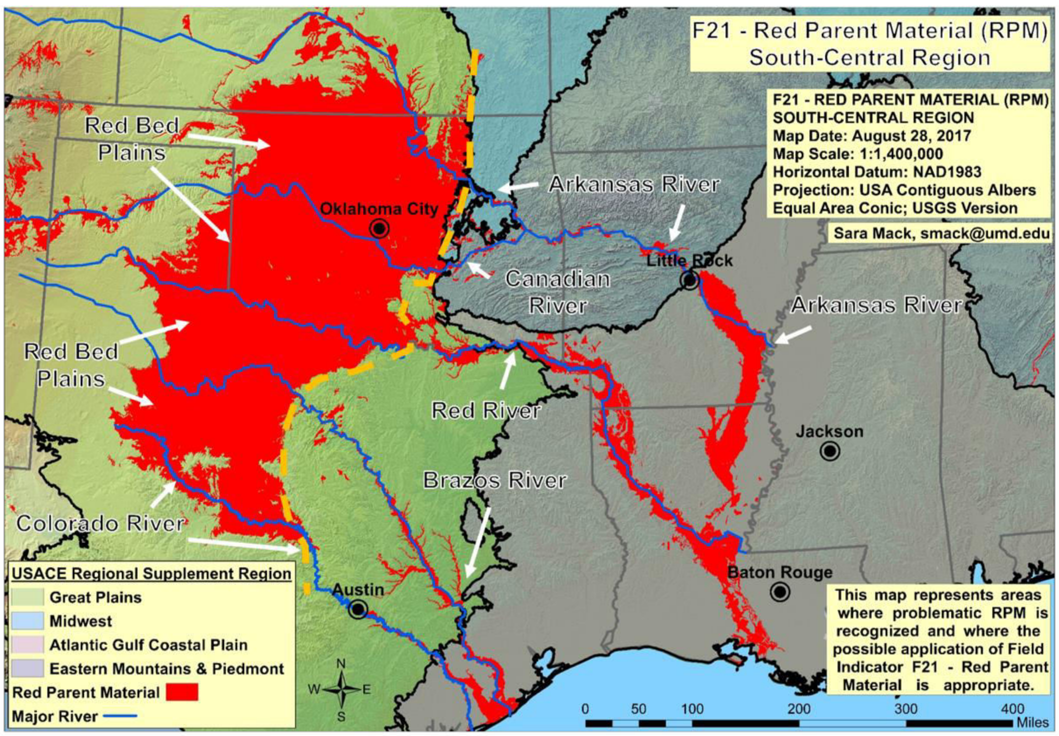

Figure 3.15. *Guidance map for appropriate application of the F21 - Red Parent Material (RPM) field indicator in the South-Central region. Red areas indicate locations with soils and geological formations where problematic RPM are possible. Note that suspected RPM soils in these areas must also meet current color requirements of the F21- Red Parent Material field indicator for application.*

Problematic RPM in the South-Central region has been identified within the states of Arkansas, Louisiana, Kansas, Oklahoma, and Texas. Problematic RPM is generally differentiated between western and eastern portions of this overall region by watershed systems that originate within the drier, bedrock-controlled areas of the Great Plains and Central Lowland physiographic provinces, and terminate as thick alluvial deposits that overly more recent, unconsolidated sediments along major river systems in the Coastal Plain province.

The western portions of this region include USDA-NRCS LRRs and MLRAs within the USACE Great Plains Regional Supplement Region (MLRAs 78A/B/C, 80A, and 80B of LRR H, 81B/C and 82A of LRR I, and 82B, 84A/B/C, 85, 86A/B, and 87A/B of LRR J) (Table 3.17). RPM in these areas typically occurs on gently rolling plains and prairies dissected with current and ancient stream terraces in its northern parts, to more eroded plateau areas with deeply entrenched streams and rivers in its southern parts (LRR H). Towards the east, RPM occurs on landscapes characterized as gently rolling to hilly uplands dissected by streams that grade into a gently sloping plain (LRR J). PRPM soils in these portions of the region are typically shallow and locally sourced from bedrock responsible for the occurrence of problematic RPM in the region.

Eastern portions of this RPM region include USDA-NRCS LRRs and MLRAs within the Atlantic Gulf Coast Plain Regional Supplement Region (MLRAs 131A/B/C of LRR O, 133B, 134, and 135 in LRR P, and 150A/B in LRR T) (Table 3.17). RPM here primarily occurs on landscapes dominated by smooth terraces, floodplains, lowlands, and deltas along major river systems (LRR O, P, T), and therefore, PRPM soils are primarily alluvial. Minor RPM areas are also possible in small portions of the Interior Highlands within the USACE Midwest and Central and Eastern Mountains Regional Supplement Regions that transition between the Coastal

Plain and Great Plains provinces in the northeast areas of the South-Central region (MLRA 112 of LRR M and MLRAs 118A/B of LRR N) (Table 3.17). RPM in these areas occurs on landscapes dominated by narrow and rolling ridges, flat-topped mountains, as well as the Boston and Ouachita Mountains, however, RPM is only associated with major river systems that dissect the areas and is also primarily alluvial. RPM in the additional fifteen MLRAs of the Western Mountains, Valleys, and Coast and Great Plains USACE Regional Supplement Regions (MLRAs 48A/B and 49 in LRR E, 67B, 79, and 70A/B in LRR G, and 72, 73, 74, 76, 77A/B/E, and 79 of LRR H; Table 3.17) is also likely alluvial, however, has not been included in RPM guidance maps for the South-Central region (see "*Central Red Bed Plains Alluvium" and "Central Red Bed Plains Alluvium: Arkansas and Red Rivers*" sections for more information).

Within the South-Central region, however, two distinctive groups of soils and parent materials have been identified where the F21 – Red Parent Material indicator may be applied:

1. Soils derived from Permian-aged, red bed formations that outcrop across the rolling red plains of northwest TX, central OK, and south-central KS.[63] This area is referred to as the Central Red Bed Plains.
2. Soils derived from reddish-colored alluvial deposits of major river systems that drain the Permian red beds of the Central Red Bed Plains to the south and southeast towards the Coastal Plain. These are sub-divided into two distinctive watershed systems –

[63] Similar Permian-aged red beds also occur north to south across central NM, northern parts of the Panhandle of TX, as well as southwestern TX. See the "*Desert Southwest and Western Mountains*" and "*Pecos River Valley*" sections of this chapter for more information.

a. The Arkansas and Red Rivers

b. The Brazos and Colorado Rivers

The following sections describe the nature of these groups of soils and parent materials that are recognized as problematic RPM (including soil series and geological formations). These areas are also highlighted on RPM guidance maps showing where the indicator may be applied. Where appropriate, additional guidance on use and application of the F21 – Red Parent Material indicator is given as "user notes."

Central Red Bed Plains

Problematic RPM of this group in the South-Central RPM region belong to a collection of mostly Permian-aged, sedimentary red bed formations that occur in an area sometimes referred to as the "Central Red Bed Plains" in north-central TX, central OK, and south-central KS (Figure 3.15). This area includes parts of several structural basins and paleo-continental shelves that contain exposures of Permian red beds of the "Greater Permian Basin" that stretches across the central U.S. (Figure 3.16).

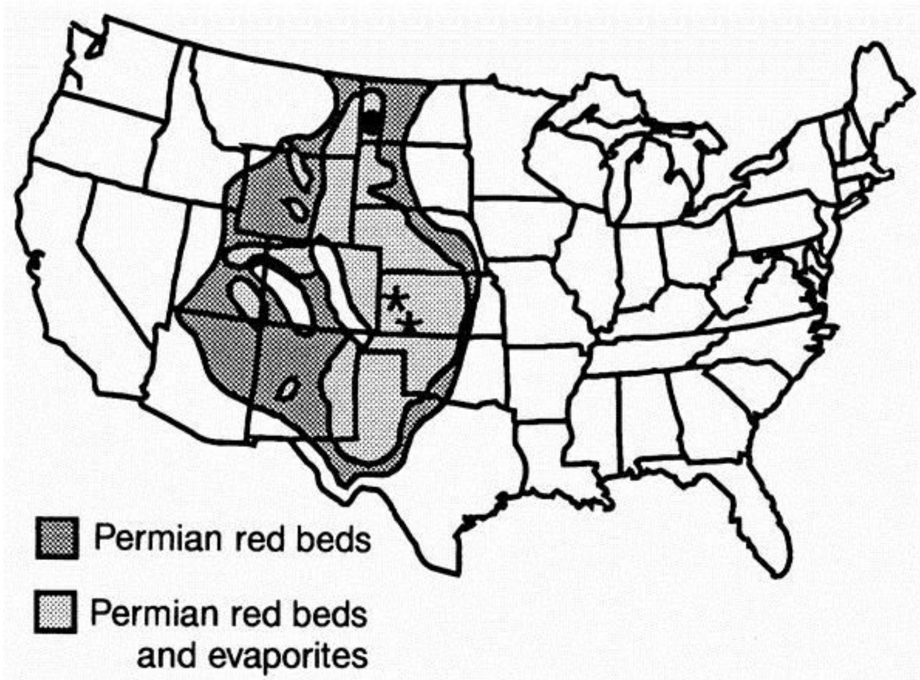

Figure 3.16. *Map showing the theoretical distribution of Permian red beds and evaporites in the United States. Figure 1 from Benison et al. (1998).*

The sediments that compose the exposed red beds in this South-Central RPM region were ultimately sourced from the erosion of the Ouachita Mountains that formed during the Ouachita-Marathon (Hercynian) orogeny between today's current Texas craton and the South American tectonic plate in the late-Pennsylvanian, early-Permian periods (~300 Mya) (Ferring, 2007; Johnson, 2008; King, 1975).[64] Streams and river systems flowing westward from the Ouachita Mountains deposited the sediments in variety of fluvial, deltaic, and shallow-marine environments that pro-graded east to west from the mountain system to infill the low-lying basin areas once submerged by a shallow sea (Aurin, 1917; Jones and Hentz, 1988; Miall, 2008).

[64] The Hercynian orogeny between the ancient North American and South American tectonic plates that formed the Ouachita Mountains lasted as long as 50 My (Farrand, 1960). During this same time, the Alleghenian orogeny (that formed the current Appalachian Mountain system in the northeastern United States) (King, 1975), and the formation of the Ancestral Rocky Mountains in the central U.S., was also occurring (Kluth and Coney, 1981; Dickinson and Lawton, 2003). The Ouachita Mountain system in this problematic RPM area of TX has since been eroded and buried by younger sedimentary rocks following the Pennsylvanian and Permian periods. Exposures of this orogenic belt are now only found in the Ouachita Mountains in western OK and eastern AR, and as the Marathon Mountains in the Big Bend area of southwest TX (Ferring, 2007).

Thick limestone deposits, along with the terrestrial sediments, were cyclically accumulated in these basins bounded on the east and south by the Ouachita Mountains as cyclical sea level changes (driven by glaciation on other parts of the supercontinent) submerged or isolated separate basins (Ferring, 2007; Johnson, 2008; Miall, 2008).

By the mid-to-late Permian period, the ancient delta systems of the area were covered with floodplains (i.e. nearly filled in with sediments) near the equator in a warm tropical climate. Intense weathering of the deposited sediments occurred during times of low sea level until the inland seas eventually dried up (Ferring, 2007; Johnson, 2008). Intense evaporation of the waters thus resulted in the deposition and formation of evaporites (accumulations of salts, gypsum, etc.) and red-colored clastic sediments that make up the red beds in this area. Today, these formations are now exposed at the surface in the Red Hills physiographic area of southern KS (Buchanan and McCauley, 2010; Zeller, 1968; Sawin et al., 2008), the Red Bed Plains of central OK (Curtis et al., 2008; Johnson, 2008), and the North-Central Plains in north-central TX (Texas Bureau of Economic Geology, 1996a; Jones and Hentz, 1988) (USDA-NRCS MLRAs 78B/C, 80A, 82B, and west sections of 84A). These red beds identified as problematic RPM are structurally contained within north-eastern parts of the Midland Basin, the Eastern Shelf, the Wichita Uplift, parts of the Palo Duro Basin, and parts of the Anadarko Basins of the southern mid-continent.[65]

The distribution of problematic RPM and their associated soils derived from the Permian red beds within the Central Red Bed Plains are shown in RPM guidance maps for the South-Central RPM region (Figure 3.15). Table 3.18 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Central Red Bed Plains.

Table 3.18. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Central Red Bed Plains.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Great Plains	H – Central Great Plains Winter Wheat and Range Region	78A – Rolling Limestone Prairie 78B – Central Rolling Red Plains, Western Part 78C – Central Rolling Red Plains, Eastern Part 80A – Central Rolling Red Prairies
	J – Southwestern Prairies Cotton and Forage Region	82B – Wichita Mountains+ 84A – North Cross Timbers+

**Note – see "Central Red Bed Plains: F21 – Red Parent Material User Notes" for guidance on application of the F21 – Red Parent Material indicator in USDA-NRCS MLRAs 82B and 84A (+). Also note that the entire area in MLRAs 78B/C, and 80A were highlighted as areas with potential problematic RPM in RPM guidance maps for the South-Central region as these MLRAs are dominated entirely by problematic (Permian red bed) geology (Figure 3.15).*

Table 3.19 lists the soil series and geological formations identified as potential problematic RPM (included in RPM guidance maps) that are associated with the Central Red Bed Plains.

[65] It should also be noted that some Mesozoic red beds (members/formations of the Dockum Group), also recognized as problematic RPM of the Central Red Bed Plains, outcrop in west TX (roughly at the eastern edge of the Midland Basin), as well as in the northern Panhandle (central parts of the Palo Duro Basin) (Lucas and Anderson, 1993; Texas Bureau of Economic Geology, 1996b). These Mesozoic beds are considered to be poorly preserved/exposed at the surface in comparison to the Permian strata that extensively outcrop in north-central parts of the state. This entire collection of red beds of the Central Red Bed Plains is also lithologically correlated to red bed strata that outcrop in the southern Midland, Central Platform, Delaware, and Tucumcari Basins that occur in eastern NM and southwestern TX (Miall, 2008; Kelly et al., 2012; Silver and Todd, 1969; King, 1934; Broadhead and King, 1987). These correlated beds were not included in RPM guidance maps for the South-Central RPM region (Figure 3.15), however, are further discussed in the "*Desert Southwest and Western Mountains*" RPM region and "*Pecos River Valley*" sections of this chapter.

Table 3.19. Geological formations and soil series identified as potential problematic RPM that are within the Central Red Bed Plains.

Geological Formation(s)		**Soil Series**			
Admiral Formation	Marlow Formation	Altus	Foard	Lugert	Roark
Archer City Formation	Doe Creek Lentil	Arnett	Frankirk	Lutie	Ruella
Bead Mountain	Verden Sandstone	Ashport	Gaddy	Madge	Rups
Formation	Lentil	Aspermont	Gageby	Mangum	Sagerton
Big Basin Formation	Moran Formation	Aydelotte	Gracemont	Masham	Selman
Bison Formation	Nippewalla Group	Beckman	Gracemore	McKnight	Shrewder
Bison Shale	Nocona Formation	Bethany	Grainola	McLain	Southside
Blaine Formation	Petrolia Formation	Binger	Grandfield	Milan	Spikebox
Elm Fork Member	Post Oak Conglomerate	Bukreek	Grant	Miles	St. Paul
Van Vacter Member	Post Oak Formation	Burford	Hardeman	Miller	Stamford
Cedar Hill Sandstone	Post Oak Sandstone	Burson	Harrah	Minco	Stoneburg
Chickasha Formation	Pueblo Formation	Callahan	Hayfork	Mulhall	Teller
Clear Fork Formation	Purcell Sandstone	Canadian	Heman	Nash	Tillman
Clear Fork Group	Quartermaster Formation	Carey	Hinkle	Nashville	Tilvern
Cloud Chief Formation	Rush Springs Formation	Chickasha	Hollister	Newalla	Tipton
Dockum Group	Weatherford Gypsum Bed	Clairemont	Huska	Nipsum	Treadway
Dog Creek Shale	Salt Plains Formation	Clearfork	Ironmound	Noble	Vernon
Doxey Formation	San Angelo Formation	Cobb	Jamash	Norge	Vinson
Doxey Shale	San Angelo Sandstone	Colorado	Jaywi	Oakley	Wakita
Duncan Sandstone	Santa Anna Branch Shale	Cordell	Jester	Obaro	Waurika
El Reno Group	Sumner Group	Cornick	Jolly	Oscar	Westola
Elk City Sandstone	Talpa Formation	Cosh	Kamay	Ozark	Westill
Elm Creek Formation	Valera Formation	Darsil	Kingco	Paducah	Westview
Fairmont Shale	Waggoner Ranch	Darnell	Kingfisher	Pawhuska	Wetbeth
Flowerpot Shale	Formation	Decobb	Kirkland	Piedmont	Weymouth
Garber Sandstone	Wellington Formation	Deepwood	Knoco	Pond	Wheatwood
Grape Creek Formation	Whitehorse Formation	Dill	Konawa	Creek	Wichita
Guadalupia Series	Whitehorse Group	Dodson	La Casa	Port	Winters
Hennessey Group	Wichita Group	Drummond	Lawrie	Pulaski	Wisby
Jagger Bend Formation	Wolfcampian Series	Duke	Lawton	Quanah	Woodward
Kingman Formation		Enterprise	Lebron	Quinlan	Yahola
Kingman Siltstone		Easpur	Lela	Reinach	Yomont
Leuders Formation		Ezell	Littleaxe	Renfrow	Zaneis
		Farry	Lovedale	Renthin	Zellmont
				Retrop	

Central Red Bed Plains: F21 – Red Parent Material User Notes

The Central Red Bed Plains within the South-Central RPM region is characterized by smooth to rolling hills with prominent ridges and valleys dissected by ancient and contemporary terraces associated with intermittent streams and major river systems. RPM soils occur throughout this landscape as residual, colluvial, eolian, and alluvial deposits derived from and/or influenced by the Permian bedrock. Residual soils consist of sandy, silty, or clayey materials related to the grain sizes of their parent formations. These soils are typically moderately deep to very shallow, and occur on convex, low ridgetops, escarpments, or interfluves in upland areas on the dissected plains (e.g. Aydelotte, Chickasha, Ironmound, Knoco, Quinlan, Tilvern, Vernon, and similar soils). Many residual soils are also calcareous (e.g. Callahan, Lutie, Woodward and similar soils), containing concretions of solid calcium carbonate sourced from marine sequences deposited with the red beds during the Permian time. Some soils are also derived directly from evaporite deposits, containing gypsum crystals or significant accumulations of salts (e.g. Cornick, Huska, Vinson, Wakita, and similar soils). The majority of these residual soils occur in western and north-central TX in the Central Rolling Red Plains (MLRAs 78B/C), in comparison to north-central OK and KS and in the Central Rolling Red Prairies (80A). Minor areas with RPM soils (e.g. Knoco, Vernon soils) are mapped in the Rolling Limestone Prairie (78A) where the underlying bedrock is composed more of gray-colored shales and limestones in comparison to the red beds. The rock sequences known to contain red beds generally grade into sequences dominated more by marine-carbonate type rocks (limestones, dolomites, etc.) in comparison to red beds to the south/southwest of the Central Red Bed Plains area (i.e. south towards the Midland, Central Platform, and Delaware Basins) (Figure 3.15). Additional CCPI analyses may prove helpful when making hydric soil determinations in these cases, as the marine bedrock in these areas is not recognized as problematic RPM like that of their associated red beds.

Residual soils derived from the Permian red beds in the North Cross Timbers (MLRA 84A) are represented by the Darnell, Darsil, Littleaxe, Newalla, and similar soils. These soils typically occur in western portions of the MLRA in central OK, and do not extend up into the southern KS portions of the MLRA where the underlying geology is Pennsylvanian-aged shales and sandstones of a different origin. RPM soils in the Central Rolling Red Prairies (MLRA 80A), as well as some minor areas in the Rolling Plains (MLRAs 78B/C), also tend to have deep, dark-colored, organic-rich surface horizons characteristic of prairie soils (e.g. Renfrow, Renthin, Stoneburg, Zaneis and similar soils), where the presence of the RPM phenomenon may be more difficult to identify towards the surface of the soil profile.

Colluvial deposits in the Central Red Bed Plains have similar characteristics to that of their residual counterparts, however, these soils are generally deeper and found on backslope and footslope positions of lower hills, sloping drainage ways and terraces (e.g. Harrah, Mulhall, Nipsum, Quanah, and similar soils). Eolian deposits derived from problematic RPM are common throughout the Central Red Bed Plains as well, occurring as fine sand and silt deposits sourced from exposed escarpments on treads, dunes, sand sheets, and risers of stream terraces (e.g. Enterprise, Grandfield, Minco, and similar soils). Towards northern OK and southern KS, very fine, browner-colored, wind-blown sands and loess deposits (that are not recognized as problematic RPM) can blanket areas where red bed geology underlies the area (e.g. Bethany, Pond Creek, and similar soils).

Furthermore, quaternary-aged, alluvial deposits sourced from the Permian red beds within the Plains are associated with several major river systems that dissect the overall rolling plain and prairie landscape. The major river systems of this area are the: Arkansas, Brazos, Canadian, Cimarron, Colorado, and Red Rivers, all which flow from the northwest to southeast across the Plains dominated by problematic

Permian red bed geology (Figure 3.15). Alluvial soils sourced from the red beds (i.e. soil series included in Table 3.19) are those mapped predominantly within the boundaries of the Central Red Bed Plains area [Central Rolling Red Plains (MLRA 78B/C), Central Rolling Prairies (80A) and some minor areas in the Rolling Limestone Prairie (78A) and North Cross Timbers (84A) (Figure 3.15)], as each river system begins and terminates outside the boundaries of the Plains in their watersheds. Most alluvial RPM soils in the Plains are mapped within the Central Rolling Prairies (MLRA 80A) in central OK, central TX, and southern KS, in comparison to the Central Rolling Red Plains (MLRAs 78B/C) in northwestern OK and TX that is drier and dominated more by residual and colluvial-type deposits.

On the landscape within the Plains, RPM soils derived from alluvium sourced from the red beds are primarily loamy to sandy (with or without coarse fragments as gravels), calcareous, and occur on nearly level floodplains, drainage ways and/or gently sloping terraces in lower areas. Ashport, Milan, Norge and similar soils are associated with the Arkansas River that flows through the north-most portions of the Plains in southern KS and northern OK (Figure 3.15). Gracemore, Miller, Port, Tillman and similar soils are associated with the Canadian, Cimarron, and Red Rivers that flow through central OK and northern TX areas of the Plains (Figure 3.15). Drummond, Pulaski, and similar soils are mapped along (Arkansas) watersheds in western portions of North Cross Timbers (MLRA 84A) where red beds are the dominant geology.[66] Clairemont, Clearfork, Colorado, Gageby, Miles, Sagerton and similar soils are primarily associated with deposition of sediments along the Brazos and Colorado Rivers in southern TX [particularly the Rolling Limestone Prairie (MLRA 78A)] (Figure 3.15). Finer textured (silty and clayey) alluvial deposits throughout the region tend to be saline or contain gypsum crystals (e.g. Beckman, Duke, Heman, and similar soils). Some soils are also recognized as lacustrine deposits in concave areas on treads of high stream terraces (e.g. Dodson), while others are recognized as ancient paleoterraces that do not grade into a present-day stream or drainage network (e.g. Hollister, Kirkland, Milan, Waurika, and similar soils). Like the residual and colluvial deposits of the Central Red Bed Plains, many alluvial soils are also known to contain dark-colored, organic-rich surface horizons typical of prairie soils (e.g. Lugert, Tipton, St. Paul, and similar soils) where the RPM phenomenon may be harder to identify towards the surface of the soil profile.

Furthermore, it should also be noted that the Wichita Mountains (MLRA 82B) falls within the boundaries of the Central Red Bed Plains area. These mountains are characterized as rocky, rounded hills or blocks composed predominantly of mafic and felsic igneous rocks (extrusive granite, rhyolite, gabbro, and anorthosite) of

[66] Some alluvial RPM soils (e.g. Burson, Canadian, Yomont, Zellmont) are mapped along the headwaters of these major rivers systems (Arkansas, Canadian, Red, etc.) located north and west of the Central Red Bed Plains (USDA-NRCS MLRAs 48A/B, 49, 67B, 69, 70A/B, 72, 73, 74, 76, 77A/B/E, and 79 indicated in Table 3.17, RPM in central and southern KS, parts of the OK and TX Panhandle, and northeast NM shown in Figure 3.15). See "*Central Red Bed Plains Alluvium*," "*Central Red Bed Plains Alluvium: Arkansas and Red Rivers*," sections for guidance on the potential use of the F21 – Red Parent Material field indicator in these areas.

Precambrian and Cambrian age (Gilbert, 1982).[67] These igneous rocks are not recognized as problematic RPM, however, some Permian red beds and their residual and colluvial soils indicated in Table 3.19 may occur in parts of the MLRA. Alluvial soils in this area are mapped primarily as granitic outwashes sourced from the mountains (e.g. Foard, Hinkle, Lawton and similar soils). These granitic outwashes are not recognized as problematic RPM, however, many can be underlain by problematic Permian red bed formations or occur in similar areas associated with alluvial deposits sourced dominantly from the red beds. Thus, these areas were included in RPM guidance maps for the South-Central region not to miss potential problematic RPM that may occur in the area.

Finally, although problematic RPM and their associated soils are very extensive in the Central Red Bed Plains, much of the area has a relatively dry climate that falls within the ustic soil moisture regime.[68] Therefore, while many of the parent materials and associated soils meet CCPI requirements of the F21 – Red Parent Material field indicator, it is not expected that extensive areas of hydric soils occur throughout the region. Nevertheless, these Permian red beds are known to be the source rocks of RPM soils in this region, as well as other soils associated with the region's watersheds outside the boundaries of the Central Red Bed Plains along the

[67] The igneous rocks of the Wichita Mountains were formed during three stages of continental rift, subsidence, and uplift that occurred in the central OK area before the Ouachita orogeny in the early Paleozoic era. Weathering and erosion that occurred during and after the Permian period exposed and produced the mantle of conglomerate blocks that the Wichita mountain system is today (Gilbert, 1982).

[68] The ustic soil moisture regime is an intermediate range between the aridic (drier) and udic (wetter) moisture regimes. The aridic moisture regime, generally, reflects a soil moisture balance where the annual precipitation is less than the potential evapotranspiration. The udic moisture regime, generally, reflects a soil moisture balance in which there is enough seasonal rain so that the amount of stored moisture plus rainfall is equal to or somewhat exceeds the amount of potential evapotranspiration. For more information on the definitions and concepts of soil moisture regimes, refer to Soil Survey Staff, USDA-NRCS (2014).

Arkansas, Brazos, Canadian, Cimarron, Colorado, and Red River systems. As a result, the F21 – Red Parent Material may be useful in identifying hydric soils in landscape positions where water accumulates and wetlands are likely to occur (USACE, 2010b).

Central Red Bed Plains Alluvium

Problematic RPM of this group in the South-Central RPM region is composed of red-colored, Quaternary-aged alluvial deposits of major river systems that source their red sediments from the Permian red beds within the Central Red Bed Plains and deposit them downstream of the Plains where the underlying and immediate surrounding geology is no longer the problematic Permian red bed geology. These major river systems are the: Arkansas, Brazos, Canadian, Cimarron, Colorado, and Red Rivers. The Arkansas and Red River systems drain the northern parts of the Central Red Bed Plains (KS, OK, northern TX),[69] while the Brazos and Colorado Rivers drain the southern parts (southern TX) (Figure 3.15). Therefore, for this document, guidance on the application for on the F21 – Red Parent Material indicator for alluvium derived from the Permian red beds has been divided into two (northern and southern) sections. As both watershed systems drain towards the southeast from the Plains, they cross many USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs. The general regions and areas through which the major rivers drain from their headwaters to their terminations have been described, however, geological and soils information and F21 – Red Parent Material user notes are mainly

[69] The Canadian and Cimarron Rivers ultimately join the main stem of the Arkansas River and are included in the drainage network of the greater Arkansas River basin. There is also a separate, smaller tributary of the Canadian river that is also called the Cimarron found entirely within New Mexico. All of these tributaries eventually drain into the larger Arkansas River.

provided for alluvial areas downstream of the Central Red Bed Plains where problematic RPM from the Plains has been transported and confirmed in occurrence via CCPI analyses.[70] In some cases, these alluvial systems compromise a relatively small portion of several USACE wetland regions and USDA-NRCS LRRs and MLRAs.

Arkansas and Red Rivers

The headwaters of the Arkansas River system originate in the Southern Rocky Mountains in CO and NM from the melting of snowpack of the Sawatch and Mosquito Mountains. The river can be divided into distinct sections along its entire ~1,500-mile flow path (Ward, 1963). The first section flows as steep, fast-flowing rivers from the mountains, across the Colorado Piedmont through canyons and gorges 50 to 100 miles from the mountain front towards southern CO. Here, the system emerges on the High Plains as meandering rivers across eastern NM and western KS. In these sections of the river, the underlying and surrounding geology is primarily characterized by Precambrian-aged, igneous and metamorphic rocks uplifted/formed along the "Front Range" of the Southern Rockies (MLRA 48A); remnants of Pennsylvanian to Cretaceous sedimentary rocks and recent (Cenozoic) volcanic flows (MLRA 49); Cretaceous and Quaternary sandstones, shales, sediments reworked by wind/water; and a variety of eolian and alluvial deposits characteristic of the Blackwater Draw and Ogallala formations (MLRAs 67B, 69) (Madole, 1991; USDA-NRCS, 2006; Karnuta, 1995). None of these bedrock materials have been identified

[70] See the *"Central Red Bed Plains"* section prior for geological and soils information relating to alluvium derived from the Permian red beds found within the Central Red Bed Plains area dominated by problematic RPM geology. Geological formations and soil series associated with these alluvial deposits are included in Table 3.19.

as problematic RPM, however, some Triassic-, Jurassic- and Permian-aged red beds (correlated to problematic RPM that has been identified in central CO and northeast NM) do outcrop in areas in the Southern Rocky Mountains, Foothills, and within the Colorado Piedmont and Raton sections of the Great Plains physiographic province (MLRAs 48A/B, 67B, and 69) (USDA-NRCS, 2006) where the upper portions of the Arkansas river flows. From here, the Arkansas then flows eastward through central KS, depositing sediments in broad floodplains in areas dominated by river-laid sediments washed from the ancestral Southern Rockies; Cretaceous to Tertiary formations consisting of cemented shales, sandstones, and chalks; Permian limestones in the far east, and recent dune and loess deposits that blanket parts of the state (MLRAs 72, 73, 74, 76, and 79) (USDA-NRCS, 2006). Alluvial deposits of the upper Arkansas River (in association with the red beds in its headwater stretches) have not been confirmed as problematic RPM (via CCPI analyses) in any of these MLRAs. For these reasons, these portions of the upper Arkansas River valley (MLRAs 48A/B, 49, 67B, 69, 72, 73, 74, 76, and 79) were not included in RPM guidance maps for the South-Central RPM region (Figure 3.15), but are worth mentioning as potential locations where problematic RPM could possibly occur along upper reaches of the Arkansas River where alluvial deposits of the river are not sourced from the Permian red beds of the Central Red Bed Plains area discussed previously.[71] Additional data may aid in further constraining the extent of problematic RPM in the upper stretches of the Arkansas River watershed. Caution (and CCPI analyses) should be used when

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[71] Some RPM soils, predominantly associated with the Central Red Bed Plains area (Table 3.19), are mapped as alluvium along the upper stretches of the Arkansas River in southern and central KS (e.g. Canadian, Enterprise, Yomont, Zellmont, and similar soils in MLRAs 72, 73, 74, 76, and 79) in RPM guidance maps for the South-Central region (Figure 3.15). Additional CCPI analyses should be used when applying the F21 – Red Parent Material field indicator in these areas.

applying the F21 – Red Parent Material field indicator in these upper watershed areas not included in RPM guidance maps for the South-Central region (Figure 3.15) More information on the Triassic, Jurassic, and Permian red beds identified as problematic RPM in the Southern Rockies, Foothills, etc. is provided in the "*Desert Southwest and Western Mountains*" section of this chapter.

From these areas, the second section of the Arkansas River passes eastward from the High Plains into the dissected rolling plains that extends through southern KS and central OK where the underlying and surrounding bedrock is composed of the problematic Permian red beds (MLRAs 78C, 80A, parts of 84A, see *Central Red Bed Plains* section prior). Here, streamflow increases and drainage courses become very numerous. Major tributaries that also flow through the Plains dominated by Permian red bed geology join the main stem of the Arkansas where the rivers are impounded in large reservoirs to maintain steady river flow for local economies. The two largest tributaries are the Cimarron and the (North and South) Canadian Rivers. It should also be noted that both the Cimarron and Canadian tributaries of the Arkansas River begin as headwater streams within or south of the Southern Rocky Mountains in southern CO and northeastern NM and flow eastward across areas known to contain Permian, Triassic, and Jurassic red beds (also recognized as problematic RPM) (MLRAs 70A/B, 77A/B/E) before entering the Central Red Bed Plains and joining the Arkansas' main stem. These MLRAs are not included in RPM guidance for the South-Central region (Figure 3.15), but are mentioned here as potential locations of problematic RPM in the upper portions of the Cimarron and Canadian River watersheds where alluvial deposits are not sourced from the Permian red beds of the

Central Red Bed Plains area discussed previously.[72] These red beds and portions of the upper watersheds of the Cimarron and Canadian Rivers are further discussed in the "*Desert Southwest and Western Mountains*" sections of this chapter.

The third section of the Arkansas River flows east from the rolling plains in a more contained channel towards eastern OK and western AR where the landscape is characterized by rugged hills and narrow, deeply incised valleys typical of the Interior Highlands (MLRAs 112, 118A/B). Here, the path of the river works between the Boston and Ouachita Mountains and many isolated, flat-topped mesas underlain mostly by non-problematic, Pennsylvanian and Mississippian-aged sedimentary rocks (hard/soft sandstones, conglomerates, and limestone) (USDA-NRCS, 2006). Closer to the mountain ranges, areas are underlain by non-problematic, Paleozoic and Precambrian-aged sedimentary and metamorphic rocks. The Arkansas River itself captures sediments eroded from these sources; it's main river valley is characterized by terrace deposits composed of discontinuous, unconsolidated, sands, silts, and clay.

The final section of the Arkansas River begins east of Little Rock, AR, where the river greatly expands as it encounters flatter land and flows for about 100 miles over a coastal plain until it joins the Mississippi River on the AR and MS border (MLRA 131B) (Ward, 1963). In the river's past, the river once continued southward on its own path to the Gulf into northern portions of LA, also depositing alluvium sourced from its northern courses. These areas are underlain by Cretaceous and

[72] Some RPM soils, predominantly associated with the Central Red Bed Plains in the South-Central RPM region (Table 3.19), are mapped as alluvium along the upper stretches of the Canadian and Cimarron river in parts of the OK and TX Panhandle, and northeastern NM (e.g. Burson, Clairemont, Colorado, and similar soils in MLRAs 70A/B, and 77A/B/E) in RPM guidance maps for the South-Central region (Figure 3.15). Additional CCPI analyses of soil samples are recommended when making F21 hydric soil determinations in these areas.

Tertiary beach and marine deposits formed during the retreat of the Cretaceous ocean from the mid-section of the U.S (not recognized as problematic RPM) (USDA-NRCS, 2006). The Arkansas River system ultimately collects problematic red sediments from the Permian red beds in the rolling plains along its drainage system. These sediments are then carried eastward across the rugged terrain between the Boston and Ouachita Mountains, and deposited over Cretaceous-aged sediments in the flatter, coastal plain areas in southwestern AR and northern LA (MLRA 131B).

Likewise, the 1,200-mile-long Red River system begins as small, intermittent streams on the High Plains in Llano Estacado, a region dominated by eolian and alluvial deposits of the Blackwater Draw and Ogallala formations (not recognized as problematic RPM) in eastern NM and the TX Panhandle (MLRA 77C) (Ward, 1963; USDA-NRCS, 2006). Like the Arkansas River, the Red also passes eastward from the High Plains into the more dissected rolling plains dominated by problematic Permian red beds (MLRAs 78B/C, 80A, see "*Central Red Bed Plains*" section prior). Here, the main channel of the river flows through the rolling plains along the TX and OK state border, where the streamflow and drainage courses also become more numerous. The river then leaves the rolling plains along the western TX/OK border towards southeastern parts of OK and southwestern AR. Here, the underlying and surrounding geology consists of primarily of interbedded, Cretaceous-aged sedimentary rocks (MLRAs 84B/C, 87B), as well as unconsolidated marine and (fluvio)deltaic sands, silts, and clays of Tertiary age (MLRAs 133B, 135B) (USDA-NRCS, 2006). None of these bedrocks materials (once the river leaves the rolling plains) have been identified as problematic RPM.

From there, the Red River meanders southeastward across central LA into the flatter coastal plain (also underlain by non-problematic, marine, Cretaceous, beach deposits associated with the retreat of the Cretaceous ocean) towards its confluence with the Mississippi River near the foot of LA (MLRA 131C). At times throughout the Quaternary, the Red River joined the Mississippi as its last western tributary, however, the modern course of the Red River is now captured but the Atchafalaya River just short of its former confluence with the Mississippi in southern LA (Autin and Snead, 1993). Sediments carried from the Red River are ultimately deposited by the Atchafalaya off-shore into the Gulf of Mexico (southernmost portions of MLRA 131A). The Red River system ultimately collects problematic red sediments from the Permian red beds in its drainage system in the rolling plains along the border of TX and OK, and deposits them over the flatter, coastal plain areas underlain by non-problematic, Cretaceous sediments in central and southern LA (MLRA 131C and in the Atchafalaya River Basin of MLRA 131A) on its path to the Gulf.

The distribution of problematic RPM and their associated soils derived from Arkansas and Red River alluvium sourced from the Central Red Bed Plains are shown in RPM guidance maps for the South-Central region (Figure 3.15). Table 3.20 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM has been confirmed (via CCPI analyses) as associated with Arkansas and Red River alluvium.

Table 3.20. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with Central Red Bed Plains alluvium of the Red and Arkansas Rivers.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Great Plains	H – Central Great Plains Winter Wheat and Range Region	78B – Central Rolling Red Plains, Western Part 78C – Central Rolling Red Plains, Eastern Part 80A – Central Rolling Red Prairies
	J – Southwestern Prairies Cotton and Forage Region	84A – North Cross Timbers 84B – West Cross Timbers 84C – East Cross Timbers 85 – Grand Prairie 87B – Texas Claypan Area, Northern Part
Midwest	M – Central Feed Grains and Livestock Region	112 – Cherokee Prairies
Eastern Mountains & Piedmont	N – East and Central Farming and Forest Region	118A – Arkansas Valley and Ridges, Eastern Park 118B – Arkansas Valley and Ridges, Western Part
Atlantic & Gulf Coast Plain	O – Mississippi Delta Cotton and Feed Grains Region	131A – Southern Mississippian River Alluvium 131B – Arkansas River Alluvium 131C – Red River Alluvium
	P - South Atlantic and Gulf Slope Cash Crops, Forest, and Livestock Region	133B – Western Coastal Plain 134 – Southern Mississippi Valley Loess 135B – Cretaceous Western Coastal Plain

**Note –this table only reflects the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where the occurrence and distribution of problematic RPM has been confirmed via CCPI analyses along the southern portions of the Arkansas and Red river systems from the Central Red Bed Plains to their termination across the Coastal Plain physiographic province. Also note that the entire area for USDA-MLRAs 131B/C were highlighted as potential RPM in RPM guidance maps for the South-Central region as these MLRAs are dominated entirely by Arkansas and Red River alluvium sourced from problematic RPM in the Central Red Bed Plains (Figure 3.15).*

Table 3.21 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where additional data may aid in further constraining the extent of problematic RPM in the upper stretches of the Arkansas and Red River watersheds north and west of the Central Red Bed Plains (southern KS, TX and OK Panhandle, eastern NM; Figure 3.15).

Table 3.21. Additional USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas possible within this study's South-Central region where application of the F21 - Red Parent Material indicator may be appropriate, but limited Color Change Propensity Index (CCPI) analyses was available.

USACE Region	**Land Resource Region (LRR)**	**Major Land Resource Area (MLRA)**
Western Mountains, Valleys, & Coast*	E – Rocky Mountain Range and Forest Region*	48A – Southern Rocky Mountains* 48B – Southern Rocky Mountain Parks* 49 – Southern Rocky Mountain Foothills*
Great Plains	G – Western Great Plains and Irrigated Region*	67B – Central High Plains, Southern Part* 69 –Upper Arkansas Valley Rolling Plains* 70A – Canadian River Plains and Valleys* 70B – Upper Pecos River Valley*
	H – Central Great Plains Winter Wheat and Range Region	72 – Central Highland Table* 73 – Rolling Plains and Breaks* 74 – Central Kansas Sandstone Hills* 76 – Bluestem Hills* 77A – Southern High Plains, Northern Part* 77B – Southern High Plains, Northwestern Part* 77E – Southern High Plains, Breaks* 79 – Great Bend Sand Plains*

**Note - this table reflects the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs along the upper stretches of the Arkansas and Red River systems from their headwaters to the Central Red Bed Plains. Alluvial deposits of these river systems have not been confirmed as problematic RPM (via CCPI analyses) in these areas, and thus, have not been included in RPM guidance maps for the South-Central region (Figure 3.15). Additional data may aid in further constraining the extent of problematic RPM in these areas. More information on the potential source rocks of the problematic RPM that may occurs in their upper watershed areas is provided in the "Desert Southwest and Western Mountains" RPM region of this chapter.*

Table 3.22 lists the soil series and geological formations identified as potential problematic RPM (included in RPM guidance maps) that are associated with Arkansas and Red River alluvium.

Table 3.22. Geological formations and soil series identified as potential problematic RPM that are associated with Central Red Bed Plains alluvium of the Red and Arkansas Rivers.

Geological Formation(s)	**Soil Series**				
Arkansas River Alluvium Canadian River Alluvium Cimarron River Alluvium Red River Alluvium	Addielou	Dougherty	Keo	Muldrow	Severn
	Armistead	Forbing	Kiomatia	Necessity	Ships
	Bastrop	Gaddy	Konawa	Norwood	Solier
	Belk	Gallion	Larton	Okay	Sonnier
	Billyhaw	Garton	Latanier	Oklared	Sterlington
	Bistineau	Glenwild	Lebeau	Perry	Stidham
	Bossier	Goodwill	Lela	Portland	Ustibuck
	Buxin	Gore	Liddieville	Porum	Wabbaseka
	Caplis	Hebert	McGehee	Redlake	Waskom
	Caspiana	Hicota	McKamie	Redport	Weswood
	Choska	Idabel	Mer Rouge	Rilla	Whakana
	Coushatta	Idee	Miller	Rodessa	Yahola
	Dardanelle	Kamie	Moreland	Roebuck	Yorktown
	Desha	Karma	Morse	Roxana	

Arkansas and Red River Alluvium: F21 – Red Parent Material User Notes

PRPM soils derived from alluvium of the Red and Arkansas Rivers, downstream of the Red Bed Plains, occur on nearly level to steeply sloping terraces, natural levees, floodplains, and/or drainage ways associated with rivers' major streams and tributaries (Figure 3.15). Along the Arkansas River in the Cherokee Plains (MLRA 112) and the Arkansas Ridges and Valleys (MLRAs 118A/B), most RPM soils are loamy to sandy, occurring as low terrace deposits confined within the valleys bound by the rugged buttes and mesas that characterize the areas (e.g. Kamie, Larton, Roebuck and similar soils). Likewise, PRPM soils along the Red River east of the Plains in the Cross Timbers and Coastal Plain areas (MLRAs 84A/B/C, 133B, 135) are loamy to sandy in texture, and occur as low stream terraces and/or natural levees (e.g. Hicota, Karma, Kiomatia and similar soils). Landscapes surrounding both these river systems are dominated typically by non-problematic, red-colored Cretaceous sediments, and therefore additional CCPI analyses may help further define potential RPM soils for hydric soil determinations in these areas.

Soils representative of problematic RPM in the lower stretches of the Arkansas and Red River watersheds in west-central AR, northern LA, and the central-southern regions of LA (MLRAs 131B/C) are the Armistead, Caspiana, Coushatta, Buxin, Forbing, Latanier, Moreland, and Yorktown soils. These soils are very clayey in texture, smectitic and superactive in their mineralogy, and primarily occur in depressional backswamp, slack water, and oxbow areas on the rivers' broad floodplains. The Glenwild soil is representative of problematic Red River alluvium found within the Atchafalaya River Basin where the Red River joins the Atchafalaya

River on its final stretch to the Gulf of Mexico. RPM soils associated with abandoned Arkansas and Red River channels in these stretches are the Herbert, Sterlington, Rilla, and similar soils.

Lastly, many PRPM soils associated with the Arkansas River near its confluences with the Mississippi River system in southern LA (MLRAs 131A, 134) are capped by a browner loamy “mantle" of alluvium and/or loess associated with the Mississippi River (e.g. Goodwill, McGehee, Idee, Perry, and Solier soils). These browner materials are not considered problematic RPM, however, the underlying red-colored alluvial sediments sourced from the Permian red beds can potentially occur at the surface in those areas. The entire landscape within the Arkansas River and Red River Alluvium MLRAs (131B/C) was mapped as problematic RPM in RPM guidance maps, as those MLRAs are dominated entirely by alluvial sediments derived from problematic RPM geology sourced in the Red Bed Plains (Figure 3.15). Again, note that alluvial deposits in headwater portions of these watersheds (particularly the Arkansas river) that occur west of the Central Red Bed Plains (MLRAs 48A/B, 49, 67B, 69, 70A/B, 72, 73, 74, 76, 77A/B/E, and 79; Table 3.21) are not included in RPM guidance maps for the South-Central region, as those landscapes were found to not contain predominant problematic RPM geology and/or lack sufficient CCPI data to confirm the presence of problematic RPM with the rivers’ deposits where possible problematic RPM is known to occur in those areas. See the “*Desert Southwest and Western Mountain*” RPM region of this chapter for more information.

Brazos and Colorado Rivers

Headwaters of both the Brazos and Colorado Rivers begin as dry, intermittent streams or "draws" on the High Plains of eastern NM and (north)eastern TX near Llano Estacado. The Brazos River, specifically, has three main tributaries consisting of very sandy, salty, slow-moving waters called the Salt, Double Mountain, and Clear Forks. The main stem of the Brazos begins at the confluence of the Salt and Double Mountain Forks in Stonewall County, TX, with the Clear Fork entering slightly more south in Young County, TX. Upper stretches of the river typically do not have enough water to sustain permanent flows until the Clear Fork joins the main stem. The main stem of the Colorado begins south of Lubbock, TX, near the rim of the High Plains escarpment. Here, the intermittent streams pass through open plains and numerous playa basins on an elevated plateau characterized by eolian and alluvial deposits of the Blackwater Draw and Ogallala formations (MLRA 77C) (USDA-NRCS, 2006). No problematic RPM has been identified in these areas.

From the High Plains, both the Brazos and Colorado Rivers flow southeastward across the rolling plains in central TX where the landscape is dominated by problematic Permian red bed geology (Table 3.19, Figure 3.15). Like the Arkansas and Red Rivers, drainage networks and river courses become very numerous for the Brazos and Colorado River systems in these areas. The Colorado River cuts through the southern-most section of the rolling plains, while the Brazos River cuts the plains in more central areas between the Colorado River basin to the south and the Red River basin to the north (Figure 3.15).

From the rolling plains, the Brazos and Colorado Rivers pass through slightly different terrain on their paths to the Gulf of Mexico in southeastern, TX. The Brazos River, specifically, passes from the rolling plains into the Central Texas Section of the Great Plains Physiographic Province and the Osage Plains Section of the Central Lowlands Province (MLRAs 78A, 80B, 84B, and 85). Here, the Brazos River flows across a dissected plain, with meander belts that are defined and controlled by weather-resistant bedrock. In these areas, the underlying and surrounding geology consists of: Permian-aged, interbedded light gray and white limestones (MLRA 78A); Pennsylvanian- and Cretaceous-aged formations that consist of light-gray limestones and browner-colored sandstones and shales (MLRA 80B); and low-lying, alternating beds of Cretaceous-aged sandstones, claystones, and conglomerates that sometimes contain marls and gypsum beds (MLRA 84B, and western edge of MLRA 85) (USDA-NRCS, 2006). None of these parent materials are recognized as problematic RPM.

Likewise, the more southern flowing Colorado River passes from the rolling prairies into the Hill Country of TX, composed of the Edward's Plateau (MLRAs 81B/C) and the Central Texas (Llano) Basin (MLRA 82A). Within the Edward's Plateau, the river flows as large channels through nearly-level to gently sloping valley floors within deep gorges and canyons composed of Cretaceous-aged, limestone bedrock that characterizes the area. In the Central Texas (Llano) Basin, tributaries of the Colorado flow on low-lying floodplains between hills and ridges underlain and composed of igneous, metamorphic, and sedimentary rocks. The igneous and metamorphic rocks are Precambrian-aged granites, gneiss, and schists associated with the Llano Uplift, representing some of the oldest rocks in the state (Ferring, 2007). The sedimentary rocks that underlie the Llano Basin are predominantly Cambrian and Cretaceous in age, represented by the Hickory and Lion Mountain Sandstone (Cambrian), and Hensell Sand (Cretaceous) (USDA-NRCS, 2006). None of these parent materials have been identified as problematic RPM.[73]

From these areas, both the Brazos and Colorado Rivers continue southeastward towards the coast to enter the flatter Coastal Plain Province (in USDA-NRCS MLRA 86A). Here, floodplains of the rivers widen significantly, and are flanked by nearly level stream terraces sometimes as far as eight miles away from the rivers' main channels (Epps, 1973). Underlying and surrounding geology consists primarily of: Cretaceous formations that contain chalks, claystones, marls and shales (MLRA 86A); Tertiary-aged sediments as calcareous clays, sandstones and marls (MLRA 86B); and (fluvio)deltatic and marine sediments of Tertiary-age as sandstones, siltstones and weakly unconsolidated sands, silts, and clays (MLRA 87A) (USDA-NRCS, 2006). The bedrock materials in these areas trend parallel to the Texas Gulf Coast, and have also not been identified as problematic RPM.[74]

Finally, the Brazos and Colorado Rivers enter the Gulf Coast Prairies onto nearly level plains of low elevation and relief (MLRA 150A). Here, deposits are deltaic and/or lagoonal clays and loams underlain by Pleistocene-aged sedimentary rocks that have been deposited during the last 2 My (USDA-NRCS, 2006). Closer to

[73] Upon exiting Hill Country, the Colorado River is heavily dammed for flood control purposes. The main impoundments are those of the Central Texas Highland Lakes, south of the Hill Country, just west of Austin, TX.

[74] Like the Colorado, the Brazos River is impounded for flood control purposes by several dams. These dams are built along the main stem as the river crosses and/or enters flatter Coastal Plain Province outside the rolling plains at Possum Kingdom Reservoir in Caddo, TX, Lake Granbury in Granbury, TX, and Lake Whitney near Whitney, TX.

the coast (MLRA 150B), floodplains of the rivers broaden as they enter saltwater bays, its lowest parts submerged by high and/or strong storm tides before entering the Gulf of Mexico southeast of Houston, TX.

The Brazos and Colorado River systems ultimately collect problematic red sediments from the Permian red beds in its drainage system in the rolling plains and carry them across dissected plains and hills underlain and composed of a variety of non-problematic, Precambrian-, Paleozoic-, and late-Mesozoic (Cretaceous) materials that characterize the geology of central and southern TX. Alluvium containing sediments derived from the Permian red beds are then ultimately deposited over the flatter, Coastal Plain and Gulf Coast Prairies in broad floodplain and deltaic environments before discharging into the Gulf of Mexico (Figure 3.15).

The distribution of problematic RPM and their associated soils derived from Brazos and Colorado River alluvium sourced from the Central Red Bed Plains are shown in RPM guidance maps for the South-Central region (Figure 3.15). Table 3.23 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with Brazos and Colorado River alluvium.

Table 3.23. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with Central Red Bed Plains alluvium of the Brazos and Colorado Rivers.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Great Plains	H – Central Great Plains Winter Wheat and Range Region	78A – Rolling Limestone Prairie 78B – Central Rolling Red Plains, Western Part 78C – Central Rolling Red Plains, Eastern Part 80B - Texas North-Central Prairies
	I - Southwest Plateaus and Plains Range and Cotton Region	81B – Edwards Plateau, Central Part 81C – Edwards Plateau, Eastern Part 82A – Texas Central Basin
	J – Southwestern Prairies Cotton and Forage Region	84B – West Cross Timbers 85 – Grand Prairie 86A – Texas Blackland Prairie, Northern Part 87A – Texas Claypan Area, Southern Part 86B – Texas Blackland Prairie, Southern Part
Atlantic & Gulf Coast Plain	T – Atlantic and Gulf Coast Lowland Forest and Crop Region	150A - Gulf Coast Prairies 150B – Gulf Coast Saline Prairies

**Note - this table reflects the USACE Regional Supplement Regions, and USDA-NRCS LRRs and MLRAs along the courses of the Brazos and Colorado rivers from the Central Red Bed Plains to their terminations across central and southern TX (Figure 3.15).*

Table 3.24 lists the soil series and geological formations identified as potential problematic RPM (included in RPM guidance maps) that are associated with Brazos and Colorado River alluvium.

Table 3.24. Geological formations and soil series identified as potential problematic RPM that are associated with Central Red Bed Plains alluvium of the Brazos and Colorado Rivers.

Geological Formation(s)	Soil Series				
Brazos River Alluvium Colorado River Alluvium	Apalo Aquilla Asa Bastrop Belk Bergstrom Brazoria Churnabog Clearfork	Clemville Coarsewood Colorado Decordova Gad Gaddy Gageby Gause Gholson	Highbank Hornsby Kopperl Mangum Miles Miller Minwells Mohat Norwood	Oklared Paluxy Pledger Rabbs Roetex Sagerton Ships Smithville	Sumpf Surfside Velasco Westola Wheatwood Weswood Winters Yahola

Brazos and Colorado River Alluvium: F21 – Red Parent Material User Notes

PRPM soils derived from alluvium of the Brazos and Colorado Rivers are found on draws, nearly level to steeply sloping terraces, floodplains, and/or drainage ways associated with the rivers’ major streams and tributaries in the lower sections of their watersheds east of the Permian Plains area (Figure 3.15). Along the Brazos River in its upper stretches in north-central TX (MLRAs 80B, 85, 86), PRPM soils are typically stratified, loamy deposits on river valleys and leveled stream terraces, sometimes reworked by wind (e.g. Decordova, Minwells, Paluxy, Wheatwood, and similar soils). Along the Colorado River in its upper stretches in central TX (MLRAs 78A, 81B/C, 86, 87), PRPM soils occur on sloping bottomlands and low terraces as loamy deposits with deep, dark-colored surface horizons typical of prairie soils (e.g. Bergstrom, Sagerton, Smithville, Rabbs and similar soils). Many soils in the region are also calcareous, and some have granitic inputs from the Llano Basin.

Soils representative of problematic RPM in the lower stretches of the Brazos and Colorado Rivers in southeastern TX (MLRA 150A) include the Asa, Brazoria, Belk, Highbank, Norwood, Pledger, Roetex, Ships and similar soils. These soils are very silty to clayey, smectitic or superactive in their mineralogy, and occur in depressions, backswamps, and slack water areas on nearly level floodplains. Churnabog and Sumpf soils are representative of soils found on older, abandoned river channels. Before reaching the Gulf (MLRA 150B), some PRPM soils are deposited as saline alluvium on depressed delta plains near sea level (e.g. Surfside, Velasco, and similar soils). Again, note that alluvial deposits in headwater portions of the Brazos and Colorado River watersheds west of the Permian Plains are not considered problematic RPM, as those landscapes were not found to contain problematic RPM geology.

Desert Southwest and Western Mountains Region

A total of 237 soil samples from 97 sites (~21% of the total 456 sites) were submitted and analyzed for CCPI from the Desert Southwest and Western Mountains region. Of these, 198 samples (81 sites) were provided from KSSL archives, 19 samples (7 sites) from USDA-NRCS soil scientists, 12 samples (5 sites) from USACE field personnel, 9 samples (3 sites) by University affiliates, and 2 samples (1 site) from private sector soil and wetland scientists. From these samples, problematic RPM has been identified for appropriate use of the F21 – Red Parent Material indicator in twenty-six USDA-NRCS MLRAs of five major LRRs. These are mostly contained within the USACE Arid West and Western Mountains, Valleys, and Coast Regional Supplement Regions, with minor areas also occurring in westernmost portions of the Great Plains Regional Supplement Region (Table 3.25).

Table 3.25. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas within this study's Desert Southwest and Western Mountains region where application of the F21 - Red Parent Material Indicator is appropriate.*

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Arid West	D – Western and Irrigated Region	32 – Northern Intermountain Basins 34A – Cool Central Desertic Basins and Plateaus 34B – Warm Central Desertic Basins and Plateaus 35 – Colorado Plateau 36 – Southwest Plateaus, Mesas, and Foothills 38 – Mogollon Transition 41 – Southeastern Arizona Basin and Range* 42 – Southern Desertic Basins, Plains, and Mountains
Great Plains	G – Western Great Plains and Irrigated Region	61 – Black Hills Foot Slopes 70A – Canadian River Plains and Valleys 70B – Upper Pecos River Valley 70C – Central New Mexico Highlands* 70D – Southern Desert Foothills*
	H – Central Great Plains Winter Wheat and Range Region	77A - Southern High Plains, Northern Part* 77B – Southern High Plains, Northwestern Part* 77E – Southern High Plains, Breaks* 77D – Southern High Plains, Southwestern Part*
	I – Southwest Plateaus and Plains Range and Cotton Region	81A – Edwards Plateau, Western Part* 81D – Southern Edwards Plateau*
Western Mountains, Valleys, and Coast	D – Western and Irrigated Region	39 – Arizona and New Mexico Mountains
	E – Rocky Mountain Range and Forest Region	43B – Central Rocky Mountains 47 – Wasatch and Uinta Mountains 48A – Southern Rocky Mountains* 48B – Southern Rocky Mountain Parks 49 – Southern Rocky Mountain Foothills*
	G – Western Great Plains and Irrigated Region	62 – Black Hills

A guidance map for the potential occurrence of problematic RPM, and therefore the appropriate application of Field Indicator F21 – Red Parent Material in the Desert Southwest and Western Mountains region, is shown in Figure 3.17, A, B, and C.

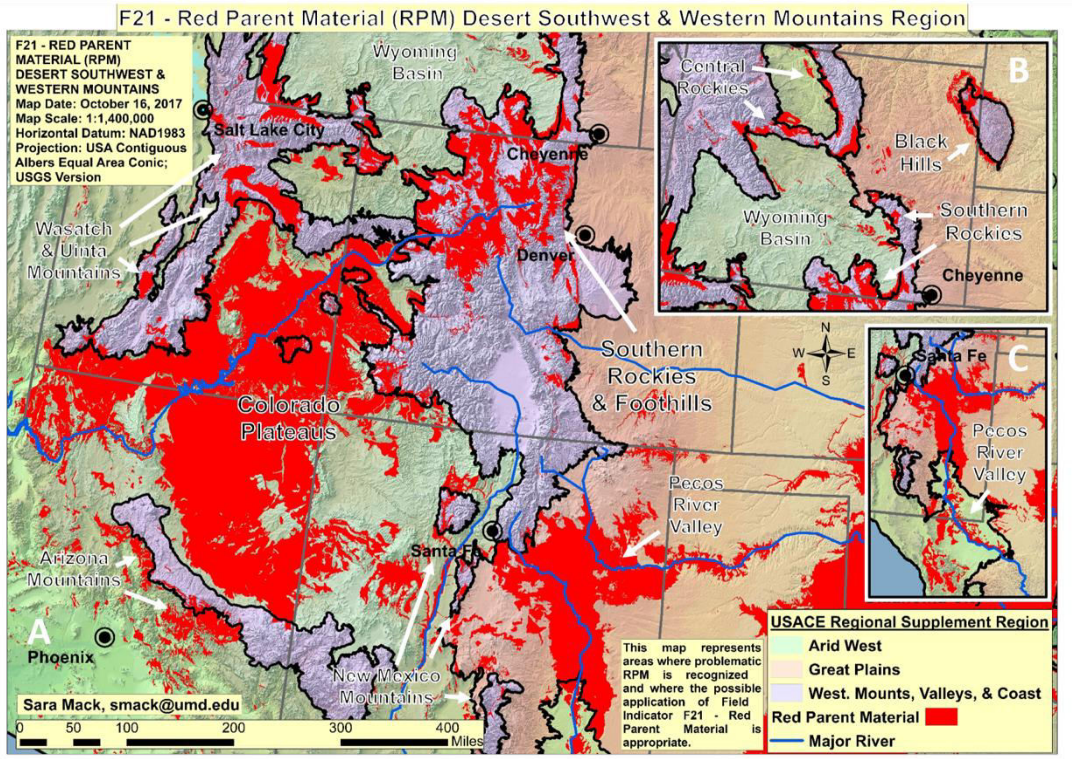

Figure 3.17. *Guidance map for appropriate application of the F21- Red Parent Material (RPM) field indicator in the Desert Southwest and Western Mountains region. Red areas indicate locations with soils and geological formations where problematic RPM are possible. Note that suspected RPM soils in these areas must also meet current color requirements of the F21-RPM field indicator for application.*

Problematic RPM in the Desert Southwest and Western Mountains region has been identified in the states of Arizona, Colorado, New Mexico, Texas, South Dakota, Utah, and Wyoming. Unlike the RPM regions discussed previously in this chapter, RPM in this region occurs within six vastly different physiographic provinces that make up the western parts of the conterminous United States: the Colorado Plateaus, Middle (Central) Rocky Mountains, Southern Rocky Mountains, Wyoming Basin, Basin and Range (Mexican Highland and Sacramento sections), and the Great Plains (Black Hills, Pecos Valley, and Edwards Plateau sections).[75] Throughout each of these provinces, the terrestrial red beds (i.e. red-colored, siliclastic sandstones, siltstones, and shales) that produce PRPM soils share a similar geological origin, and have been preserved and exposed throughout the landscapes in a variety of canyons, gorges, mountain ranges, etc. Many attempts to stratigraphically correlate these red bed formations across different landscapes and political boundaries for mapping, oil exploration, and other purposes have been made in the scientific literature as well (Darton, 1904; Branson, 1927; Reeside, 1929; Lucas and Anderson, 1998; Pipiringos, 1968; Baker et al., 1947).[76] For these reasons, Table 3.26 lists all the geological formations identified as potential problematic RPM (included in RPM guidance maps) for the entire Desert Southwest and Western Mountains region (Figure 3.17, A, B, and C), and groups of problematic RPM and their associated soils in this RPM region are further categorized in this chapter based on similarities in regional physiography and general location of occurrence (in comparison to categorizing groups of problematic RPM across multiple areas of differing

[75] Several orogenies and other tectonic activities (dated from the mid-Jurassic period to mid-Cenozoic era and largely originated from the west coast) have resulted in the formation of several large and isolated mountain ranges that bisect flatter basins and plateaus. This tectonic activity has produced the highly variable topographic and climatic landscape that characterizes the western half of the United States.

[76] The stratigraphic correlation performed on the red bed formations in this region dramatically convolutes the nomenclature used to describe and identify these formations in geological datasets that were used to map problematic RPM (see "*Materials and Methods: Identification of Problematic Red Parent Material*" and "*Generation of F21 – Red Parent Material Guidance Maps*" sections of this chapter). Thus, identifying all possible red bed formations that can produce PRPM soils in this RPM region (both within specific areas as well as across different areas) was difficult. More information on challenges and data limitations to identify and map problematic RPM in RPM guidance maps (particularly for this RPM region) are described in the "*Data Limitations, Caveats, and Future Work*" section of this chapter.

physiography and location based on a similar lithological relationships like the problematic RPM described in the previous sections of this chapter).[77]

Table 3.26. Geological formations identified as potential problematic RPM that are within the Desert Southwest and Western Mountains region.*

Geological Formation(s)		
Abo Formation*	Curtis Formation	Morrison Formation
Ankareh Formation (+)	Dinwoody Formation (+)	Naco Group
Arapien Formation	Dockum Formation	Navajo Sandstone
Arcturus Formation	Dockum Group	Nugget Sandstone (+)
Artesa Sequence	Dolores Formation	Park City Formation
Artesia Group*	Eagle Valley Formation (+)	Pitoikam Formation
Graysburg Formation*	Entrada Formation	Purgatoire Formation
Seven Rivers Formation*	Entrada Sandstone	Quartermaster Formation*
Tansill Formation*	Fountain Formation	Ralston Creek Formation
Queen Formation*	Gardner Canyon Formation	Recreation Red Beds
Yates Formation*	Glen Canyon Formation	Rudolfo Red Beds
Bull Canyon Formation	Glen Canyon Group	San Rafael Group
Burro Canyon Formation	Glen Canyon Sandstone	Satanka Shale
Bursum Formation*	Goose Egg Formation (+)	State Bridge Formation (+)
Carmel Formation	Grand Canyon Supergroup	Spearfish Formation (+)
Casper Formation	Nankoweap Formation	Summerville Formation
Chinle Group	Guadalupian Series?	Sundance Formation
Chinle Formation	Gypsum Spring Formation (+)	Supai Group
Garita Creek Formation	Ingleside Formation	Thaynes Formation (+)
Redonda Formation	Hermit Formation	Wanakah Formation
Rock Point Formation	Hermit Shale	Wingate Sandstone
Santa Rosa Formation	Jelm Formation	Woodside Formation (+)
Shinarump Conglomerate Member	Junction Creek Sandstone	Woodside Shale (+)
Chugwater Formation (+)	Kayenta Formation	Vampire Formation
Chugwater Group (+)	Lykins Formation	Yeso Formation*
Chupadera Formation*	Lyons Formation	Yeso Group*
Cutler Group	Lyons Sandstone	Zuni Sandstone
Cedar Mesa Sandstone	Maroon Formation	
Cutler Formation	Mahogany Formation	
Organ Rock Formation	Moenkopi Formation	
Organ Rock Shale	Moenave Formation	

[77] It should also be noted that many of these red bed formations (Table 3.26), and those similar to them, have been correlated to red beds exposed/mapped in a variety of other areas in the west-central United States, including, but not limited to: the Colorado Piedmont and Raton areas east of the Southern Rocky Foothills (USDA-NRCS MLRA 67B, 69) (USDA-NRCS, 2006) (these areas may currently be drained by the Arkansas River into central and southern KS); the Dry Cimarron River Valley in northeastern NM/western Panhandle of OK (Lucas et al., 1987); the Red Desert of the Wyoming Basin in south-central WY (Lageson et al., 1979); as well as several other mountain ranges and basins in the states of Montana, the Dakotas, and Idaho (Turner and Peterson, 1999). These correlated areas have not been confirmed to contain problematic RPM via CCPI analyses, and therefore were not included in RPM guidance maps for the Desert Southwest and Western Mountains region (Figure 3.17). Exposures of these correlated formations have, however, been confirmed as problematic RPM in the Colorado Plateaus physiographic province and parts of the Pecos River Valley in north-central NM (see "*Colorado Plateaus*" and "*Pecos River Valley*" sections for more information). Additional data collection and CCPI may aid in better understanding the occurrence and distribution of problematic RPM in the Desert Southwest and Western Mountains region (Figure 3.17) overall.

**Note –The nomenclature of the formations listed in this table can vary based on: 1) the location of their occurrence, and 2) attempts to correlate the deposits across the region in the scientific literature. Therefore, this list of formations does not intend to capture all red bed deposits that are likely to produce problematic RPM in the region, but instead offer guidance when applying the F21 – Red Parent Material field indicator in red soils derived from other red deposits in the region that have similar characteristics (ages, colors, structures, etc.) to those mentioned in this table. Overall, additional CCPI data may help to further constrain the extent of PRPM soils associated with many of the formations listed in this table, as well as all other possible formations that can produce PRPM soils in this region. See the remaining sections of this chapter for information on the locality of these formations and the soils derived from them to appropriately apply the F21 – Red Parent Material field indicator. These formations were identified as problematic RPM based on the limited CCPI analyses available at the time of the generation of this chapter. No comment was provided to remove these areas mapped as problematic RPM from this region when draft maps were open for public comment.*

Generally, most of the sediments that compose the red bed formations of the Desert Southwest and Western Mountains region (Table 3.26) were deposited between the late-Pennsylvanian through the late-Jurassic periods,[78] and have since been uplifted and/or structurally altered by the tectonic processes that have formed the current Rocky Mountain system today. From these formations, problematic RPM occurs as residual, colluvial, eolian, and alluvial deposits derived from the terrestrial red beds in semi-desert to desert areas characterized by plateaus, plains, and basins (LRR D), in rugged, mountain ranges surrounded by broad valleys and remnants of high plateaus (LRR E), and on the western edges of the elevated piedmont plain at the foothills of the Rocky Mountains (LRR G) (USDA-NRCS, 2006). The following groups of problematic RPM and their associated soils where the F21 – Red Parent Material field indicator may be applied in the Desert Southwest and Western Mountains region are:

1. Soils derived from red bed formations that occur within and in close association with the mountainous regions defined within the USACE Western Mountains, Valleys, and Coast Regional Supplement Region (USACE, 2010a). This sub-region includes RPM identified in mountains

[78] Some older Precambrian- and Paleozoic-aged deposits may also be recognized.

and their surrounding foothills and basins of the Middle (Central) and Southern Rockies, the Black Hills (USDA-NRCS MLRAs 61 and 62), the mountainous terrain in Arizona and New Mexico (USDA-NRCS MLRA 39), and the Wasatch and Uinta Mountains (USDA-NRCS MLRA 47).[79]

2. Soils derived from red bed formations that occur within the Colorado Plateaus physiographic province. This is a general area that includes the plateaus and canyons in and surrounding the “Four Corners Region” of the southwestern U.S. (southwestern CO, southeastern UT, northeastern AZ, and northwestern NM).
3. Soils derived from red bed formations of east-central NM, the northeastern Panhandle and southwestern portions of TX. Problematic RPM and their associated soils occur predominantly within or closely associated with the Pecos River Valley (Tucumcari and Delaware Basins).[80]

Again, the red bed formations identified as problematic RPM (Table 3.26) can occur and derive RPM soils across each of these areas in the Desert Southwest and Western Mountains region. White the field indicator F21 – Red Parent Material should be applied in the identified areas, additional data collection may help to further constrain the distribution of problematic RPM in this RPM region overall.

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[79] Red beds that occur in this region (Triassic and Jurassic) may also be correlated to the red beds identified as potential problematic RPM in the upper stretches of the Arkansas River watershed discussed in the South-Central RPM region of this chapter previously. See “*Central Red Bed Plains Alluvium*” and “*Arkansas and Red Rivers*” sections for more information. This group of problematic RPM also includes problematic RPM that occurs in the Basin and Range province along the Rio Grande Rift in central NM.

[80] The Pecos River and the upper headwaters of the Canadian and Cimarron Rivers (discussed previously in the “*South-Central*” sections of this chapter) drain parts of this sub-region. Some of the red beds in the Pecos River Valley are also correlated to red bed formations identified as problematic RPM in the South-Central RPM region discussed previously. See the “*Central Red Bed Plains,*” and “*Arkansas and Red Rivers*” sections of this chapter for additional information.

Western Mountains and Basins

Problematic RPM of this group belong to a collection of soils derived from red bed formations that occur within and in close association with the mountainous areas defined within the USACE Western Mountains, Valleys, and Coast Regional Supplement Region (USACE, 2010a) (Figure 3.17, A and B). Because this group of problematic RPM includes the collection of all mountain ranges and surrounding basins that characterize the western half of the conterminous United States, this group of problematic RPM is further divided (and described) into three additional divisions for this section of this chapter:

1. The Middle (Central) and Southern Rocky Mountains physiographic provinces (LRR E) and their immediate surrounding basins of the Rocky Mountain system;[81]
2. The Black Hills (USDA-NRCS MLRAs 61 and 62); and
3. The Arizona and New Mexico Mountains (USDA-NRCS MLRA 39) and their immediate surrounding basins of the Basin and Range (LRR D; Rio Grande Rift, Mexican Highland and Sacramento sections).

The distribution of problematic RPM and their associated soils in all areas of the Western Mountains and Basins sub-region are shown in RPM guidance maps for the Desert Southwest and Western Mountains region (Figure 3.17, A, B, and C). Table 3.27 indicates the specific USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with all areas defined the Western Mountains and Basins sub-region.

[81] Parts of the Wasatch and Uinta Mountains (USDA-NRCS MLRA 47) are also included in this division.

Table 3.27. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Western Mountains and Basins sub-region.*

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Arid West	D – Western and Irrigated Region	32 – Northern Intermountain Basins* 34A – Cool Central Desertic Basins and Plateaus* 34B – Warm Central Desertic Basins and Plateaus* 36 – Southwestern Plateaus, Mesas, and Foothills*^ 38 – Mogollon Transition^ 41 – Southeastern Arizona Basin and Range^ 42 – Southern Desertic Basins, Plains, and Mountains^
Great Plains	G – Western Great Plains and Irrigated Region	61 – Black Hills Foot Slopes+
Western Mountains, Valleys, and Coast	D – Western and Irrigated Region	39 – Arizona and New Mexico Mountains^
	E – Rocky Mountain Range and Forest Region	43B – Central Rocky Mountains* 47 – Wasatch and Uinta Mountains* 48A – Southern Rocky Mountains* 48B – Southern Rocky Mountain Parks* 49 – Southern Rocky Mountain Foothills*
	G – Western Great Plains and Irrigated Region	62 – Black Hills+

**Note – USDA-NRCS LRRs and MLRAs at the foothills, and those that contain the immediate surrounding basins on the fringe of the mountainous ranges in this sub-region, have also been included with RPM guidance maps for the Desert Southwest and Western Mountains (Figure 3.17). This was done to prevent the exclusion of potential problematic RPM that can occur in transitional zones between mountainous areas known to contain problematic RPM and their surrounding areas of lower elevation. USDA-NRCS MLRAs indicated with a "*" are those associated with the Middle and Southern Rockies; USDA-NRCS MLRAs indicated with a "+" are those associated with the Black Hills; and USDA-NRCS MLRAs indicated with a "^" are those associated with the "Arizona and New Mexico Mountains." All problematic RPM has a similar origin to that described in the "Middle and Southern Rockies" section of this chapter. See appropriate sections for information on the locality of problematic RPM in each of these areas.*

Table 3.28 lists the soil series identified as potential problematic RPM (included in RPM guidance maps) that are associated with all areas defined in the Western Mountains and Basins sub-region. Table 3.26 lists the potential geological formations that can derive these soils, and the origin/formation of them across this entire sub-region is described in the "*Middle and Southern Rockies, Basins and Foothills*" section of this chapter. At times, many of the RPM soils of this sub-region occur across multiple divisions of the Western Mountains and Basins sub-region, as the geological origins of their source rocks are interrelated.

Table 3.28. Soil series identified as potential problematic RPM that are associated with the Western Mountains and Basins sub-region.

Soil Series				
Almy	Gypnevee+	Perrypark	Sandark+	Tilford+
Barnum+	Gystrum	Pimsby	Schooner	Tinytown
Bernal	Lamphier	Plome	Scout	Tours
Boyett	Lonetree	Podo	Sinkson	Vale
Chaseville	Miracle	Red Spur	Sixmile	White House^
Cheesman	Monticello	Redbank	Southfork	Wycolo
Connerton	Nevee+	Redridge	Spearfish+	Yahmore+
Contention^	Neville	Redtom	Swint+	
Fortwingate	Nuffel	Rekrop	Tampico	
Garber	Palma^	Rizno	Thermopolis+	
Gove	Peralta^	Rule	Tieside	

Note - Soil series indicated with a + are those associated with red bed formations in the Black Hills area described in the "Black Hills" section of this chapter. Soil series indicated with a "^" are those associated with red bed formations that occur along the Rio Grande Rift and Basin and Range areas described in the "Arizona and New Mexico Mountains" section of this chapter. Many of these soil series are also mapped in the Colorado Plateaus physiographic province (another sub-region of problematic RPM in the Desert Southwest and Western Mountains region). See the "Colorado Plateaus" section of this chapter, Table 3.30 for comparison.*

The Middle and Southern Rocky Mountains, Basins, and Foothills

The Rocky Mountain system is a collection of ranges and basins that stretch from Canada, north to south across the western United States, where problematic RPM has been identified in three of the four physiographic provinces that make up the Rockies: the Middle (Central) Rocky Mountains, the Southern Rocky Mountains, and the Wyoming Basin.[82] The Southern Rocky Mountains physiographic province consists primarily of two mountain belts of strongly sloping to precipitous mountain ranges that trend north to south, mainly in CO and NM, along the border the Colorado Plateaus. Of these ranges where problematic RPM is possible to occur include the Sangre de Cristo, Laramie, and Front Range mountains in the east, and the San Juan, Sawatch, and Park Range mountains in the west (Figure 3.17, A). The Middle (Central) Rocky Mountain physiographic province consists of several mountains belts that stretch along the border of ID and WY, and into MT and UT. Of these mountain

[82] To date, problematic RPM has not been identified in the Northern Rocky Mountain physiographic province. Information in this chapter is based on the data and CCPI analyses available at the time of this chapter's generation.

ranges where problematic RPM is possible to occur include the Absaroka Range, Big Horn Mountains, Wyoming Range, Owl Creek Mountains, and Wind River Range that borders the Wyoming Basin province in northwestern and central WY[83] (Figure 3.17, A and B), as well as the Wasatch Range and Uinta Mountains that borders both the Wyoming Basin, Uinta Basin, and Colorado Plateaus across northern and eastern UT (Figure 3.17, A and B).[84] Structural basins on the fringe and between each of these mountain systems, such as the Wyoming Basin in southern WY, and the Uinta and Piceance Basins in eastern UT/western CO, are also included in this sub-region as associated with the red beds of the Rocky Mountains system not to miss possible problematic RPM in transitional zones that grade into lower elevation areas. At times, some of these transitional zones that grade out of the Southern Rocky, Wasatch, and Uinta mountains are also included in the Colorado Plateaus physiographic provinces, another sub-region where problematic RPM has been identified and described for the Desert Southwest and Western Mountains region (see "*Colorado Plateaus*" section of this chapter for more information).

Regarding problematic RPM, however, the deposition of sediments that formed the red beds that derive PRPM soils in these areas (Table 3.26) ultimately began with building of the Ancestral Rocky Mountains (i.e. the Ancestral Uncompahgre and Frontrangia ranges), roughly in the center of the contemporary North American continental plate (CO and the surrounding states) in the late-

[83] The Wyoming Basin is an elevated depression with numerous basins that are separated by uplifts and other structural features associated with the formation of the surrounding Rocky provinces (Figure 3.17, A and B).

[84] Parts of the Wasatch and Uinta Mountains (USDA-NRCS MLRA 47) transition/include areas in the High Plateaus section of the Colorado Plateaus physiographic province (another sub-region of the Desert Southwest and Western Mountains region where problematic RPM has been identified). See the "*Colorado Plateaus*" section of this chapter for more information.

Paleozoic (Late Pennsylvanian to early Permian ~320-240 Mya) (Dickinson and Lawton, 2003; Kluth and Coney, 1981).[85] At the peak of their uplift in the mid-Pennsylvanian period, the mountains were broad, "islands," surrounded by oceans near the equator. Towards the end of the Permian to early-Triassic, the mountains were weathered away as the seas receded and climates shifted towards warm and tropical, and arid and dry (Peterson and Smith, 1986; Haun and Kent, 1965; Rocky Mountain Association of Geologists, 1972). During this time, rivers and streams carried these sediments from these mountains towards the surrounding and receding oceans, and deposited them in braided river plains and near-shore, marginal-marine and delta-mudflat environments towards the coasts. Red bed formations (sequences of red-colored shales, siltstones, and sandstones) that represent these general time periods and environments (Pennsylvanian to the late-Permian/early Jurassic periods) are the Fountain, Lykins, Lyons, and similar formations, mapped mostly in the Southern Rockies (along the Front Range and Foothills) (Hubert, 1960); or the Casper (Miller and Thomas, 1936), Goose Egg (Burke and Thomas, 1956), Satanka Shale (Chen and Boyd, 1997), and similar formations in the Middle Rockies (ranges in central WY) (Table 3.26, Figure 3.17, A and B).[86]

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[85] The formation of the Ancestral Rockies was tectonically unusual. Most continental mountain ranges are formed relatively close to the coast/location of oceanic plate subduction under a continental plate (~200 miles), however, the Ancestral Rockies were formed more than 1,000 miles inland. The most supported theory for their formation is suturing/significant deformational stresses that originated from the Ouchita-Marathon orogeny in the south-east (TX) and translated north to form two broad mountain ranges, the Ancestral Uncompahgre and Ancestral Front Range (Frontrangia) (Dickinson and Lawton, 2003; Kluth and Coney, 1981) (see the "*South-Central*" and "*Central Red Bed Plains*" sections of this chapter for more information on this orogeny). During this same time, the Alleghenian orogeny that formed the current Appalachian Mountains in the Mid-Atlantic was occurring, and the supercontinent Pangea was almost completed.

[86] These formations can have differing nomenclature and/or lithological characteristics depending on their area of occurrence.

With the rifting of the supercontinent Pangea, beginning in the Triassic, the contemporary North American plate was pushed westward and the convergent boundary at the western margin of the North American continental plate ultimately formed a series of other mountains ranges to the west (via the Sonoma, Nevadan, Sevier, etc. orogenies) (Lawton, 1994). Sediments from these early mountains were carried eastward towards the flatter, eroded Ancestral Rockies and deposited by fluvial (i.e. riverine, lacustrine, deltaic) and eolian processes in a time where the region alternated between forested and temperate, tropical and marginal-marine, and aridic and dunal environments throughout the Triassic and late-Jurassic periods (Haun and Kent, 1965; Rocky Mountain Association of Geologists, 1972; Brenner and Peterson, 1994; Williams and Chronic, 2014). Red bed formations that generally represent these time periods and environments are the Morrison (Turner and Peterson, 2004), Chugwater (Picard, 1965), Jelm (Pipiringos, 1968), and similar formations (Table 3.26, Figure 3.17, A and C).

At the turn of the Cretaceous (~100 Mya), the Cretaceous-Interior Seaway entered into the center of the North American plate and would submerge most of the area currently occupied by the Rocky Mountains system and immediate surrounding areas. The overall region existed primarily in coastal plain/swamp, and near-shoreline/shallow marine environments for the next ~25-30 My (Finn and Johnson, 2005). By the late Cretaceous to the beginning of the Cenozoic era (~75-60 Mya), the sea had receded eastward and a convergent margin again developed at the west of the contemporary North American plate, marking the beginning of the Laramide orogeny (English and Johnston, 2004). During this time, deep-skinned (Precambrian) basement rocks and those on its surface were uplifted and deformed in several pulses from existing faults created from the formation of the Ancestral Rockies.[87] The uplift resulted in the formation of today's current mountain ranges, as well as the intermontane, structural basins and plateaus that currently characterize the region today. As a result, the red beds that derive problematic RPM in these areas were uplifted, squeezed, and otherwise deformed at the surface into great folds along/in direction of the faults that formed the variety of mountain ranges in this region. Today, the red beds routinely occur throughout these mountain ranges amidst a multitude of other rocks (igneous, metamorphic, and sedimentary, spanning much of the geological time scale in age), in mountain ranges and intermontane basins also elevated, altered, and eroded following their uplift since the end of Laramide orogeny ~40-35 Mya. Epierogenic uplifting has been also been gradually uplifting the entire region to their present-day elevations (Eaton, 2008), and areas of highest elevation have been and/or are currently characterized by glaciers/glacial deposits since the Wisconsinan glaciation in the Pleistocene (Pierce, 2003).

The Middle and Southern Rocky Mountains, Basins and Foothills: F21 – Red Parent Material User Notes

PRPM soils, defined in the Middle and Southern Rocky Mountains provinces (Table 3.28), occur primarily as residual, alluvial, and colluvial deposits, on a variety of landforms that characterize the mountainous and intermontane landscapes. Generally, all soils identified as problematic RPM in this sub-region occur in very

[87] Like the events that built the Ancestral Rockies; the Laramide orogeny was also tectonically unusual with large mountain ranges forming more than ~1000 miles inland from an active subduction zone. The theory for their formation is currently debated, however, it is postulated that the mountains formed by increased frictional forces caused from shallow angles of oceanic subduction at the western convergent margin of the contemporary North American plate (English and Johnston, 2004).

close proximity to the location of their source rocks, and the characteristics of the soils are mostly dependent on the lithological characteristics of their parent formations (grain sizes, mineralogy, etc.). Soils identified as problematic RPM in these areas also possess similar characteristics depending on the specific mountain ranges and basins they occur in across the region. For these reasons, user notes for PRPM soils in this section of this chapter are described for specific groups of mountain ranges that occur in the Middle and Southern Rocky physiographic provinces.

To begin, soils identified as problematic RPM in the Southern Rocky province can be divided into east and west ranges. Eastern ranges primarily include the Front Range and Laramie mountains, and western ranges include the San Juan, Sawatch, and Park Ranges (Figure 3.17, A and B). Soils identified as problematic RPM in the eastern ranges are mostly arkosic, coarse/sandy in texture, contain a predominant amount of rock fragment (as gravels, cobbles, etc.), and are derived from sandstones of the Lyons, Lykins, Fountain, and similar formations. Residual soils derived directly from these red bed formations are shallow to bedrock and occur on elevated, bedrock-controlled landforms in the landscape, such as upland hills and ridge crests (e.g. Boyett, Cheesman, Rule, Tieside, and similar soils). Likewise, colluvial and alluvial soils occur in lower landscape positions, with alluvial deposits including both those of active stream/river networks, as well as “slope alluvium” where sediments are washed downslope of upland areas into lower basins and valleys. These colluvial and alluvial soils tend to be deeper, stratified, have an increased amount of rock fragment (gravels, cobbles, etc.) and occur on alluvial fans, valley side-slopes, stream valleys, terraces, and drainageways in the landscape (e.g. Chaseville, Garber, Gove, Lonetree, Redtom, Perrypark, and similar soils). Soils identified as problematic RPM in the western ranges are similar to those of the east when derived from similar sandstone bearing formations, however, soils identified as RPM in the west ranges tend to occur at higher elevations, and therefore can be deposited and/or re-worked by glacial and peri-glacial processes (e.g. frost churning, cryoturbation) associated with glaciers that covered and currently cover the mountain tops since the Pleistocene. Residual soils in these landscapes occur on upland hills, plateaus and ridges (e.g. Miracle and similar soils), while alluvial and colluvial deposits occur on alluvial fans, concave mountain and valley side slopes, as well as drainageways and floodplains between mountainous areas in lower landscape positions (e.g. Lamphier, Scout, Tampico, and similar soils). Westernmost ranges of the Southern Rocky provinces also contain RPM soils that transition into areas of the Colorado Plateaus province. Soils here tend to be alluvial, colluvial, and/or eolian in their deposition, occurring on alluvial fans, high terraces, and plateaus of relatively lower elevation (e.g. Fortwingate, Monticello, Rizno, Tours, and similar soils).

Soils identified as problematic RPM in the Middle (Central) Rocky Mountains are mostly associated with red bed deposits in the Big Horn Mountains, Wind River Range, Owl Creek Mountains, and their immediate adjacent areas in the Wyoming Basin (Figure 3.17, A and B). Compared to the PRPM soils of the Southern Rockies, soils recognized as problematic RPM in these areas are more loamy and silty in texture and tend to be more calcareous or gypsiferous (contain accumulations of calcium carbonate and gypsum crystals) as associated with evaporite deposits that also occur with the red bed formations identified as problematic RPM in the region. Residual soils derived directly from bedrock occur in higher landscape positions in the landscape, such as ridges and hillsides of uplands (e.g. Gystrum, Gypnevee, Rekop, Spearfish, and similar soils), while alluvial/colluvial deposits occur in lower landscape positions and in intermontane basins as "slope alluvium" washed from upland areas and/or deposits of active stream/river networks. These soils occur on eroded alluvial fans, stream valleys, valley fills, terraces, and recent floodplains between mountainous areas across the Middle Rocky Mountain ranges (e.g. Almy, Neville, Redbank, Sinkson, Thermopolis, and similar soils). Soils representative of possible problematic RPM in the Wasatch and Uinta mountains and basins include the Podo, Red Spur, Scout and similar soils.

Across all of these mountainous areas, most soils identified as problematic RPM can be mixed and/or derived from materials weathered from a variety of bedrock sources other than the red beds also uplifted during the Laramide orogeny. Therefore, knowledge on the locality of red bed formations that derive PRPM soils in these areas is important when making F21 hydric soil determinations. Because many of the red beds are also associated with the occurrence of marine sequences and evaporites (limestones, dolomites, gypsum, etc. not recognized as problematic RPM) also deposited during the late-Pennsylvanian to late-Jurassic periods, knowledge on the characteristics of the red bed formations is also important when making F21 hydric soil determinations in these areas. Many of these PRPM soils in the region also possess dark-colored, organic rich surface horizons characteristic of prairie soils (i.e. mollic epipedons/Mollisols) that can mask the red color of the soils near the surface and CCPI data to confirm PRPM soils is also lacking in many areas where red bed formations are known to occur. For these reasons, additional CCPI analyses may be helpful to confirm F21 hydric soil determinations in these areas.

The Black Hills

The Black Hills (USDA-NRCS MLRA 61 and 62) is an isolated mountain range that rises above the Great Plains physiographic province in northeastern Wyoming and extends into southwestern South Dakota (Figure 3.17, B). The mountain range is the easternmost extent of the Laramide orogeny that formed the current Rocky Mountains, uplifted to form a structural, elliptical, shaped "dome" that resembles that of a target (Trimble, 1980; Lisenbee, 1988). The core of the dome is composed of basement Precambrian rocks (mostly granite, a variety of metamorphic rocks) at the highest elevations, with concentric rings of younger sedimentary rocks that dip away and down in elevation from the core. Problematic RPM in this area is associated with late-Permian to late-Jurassic red beds located in a depressional valley that wraps around the base of the dome, commonly known as the "Red Valley" or "Red Racetrack" (Figure 3.18; 3.17, B) (USDA-NRCS, 2006).

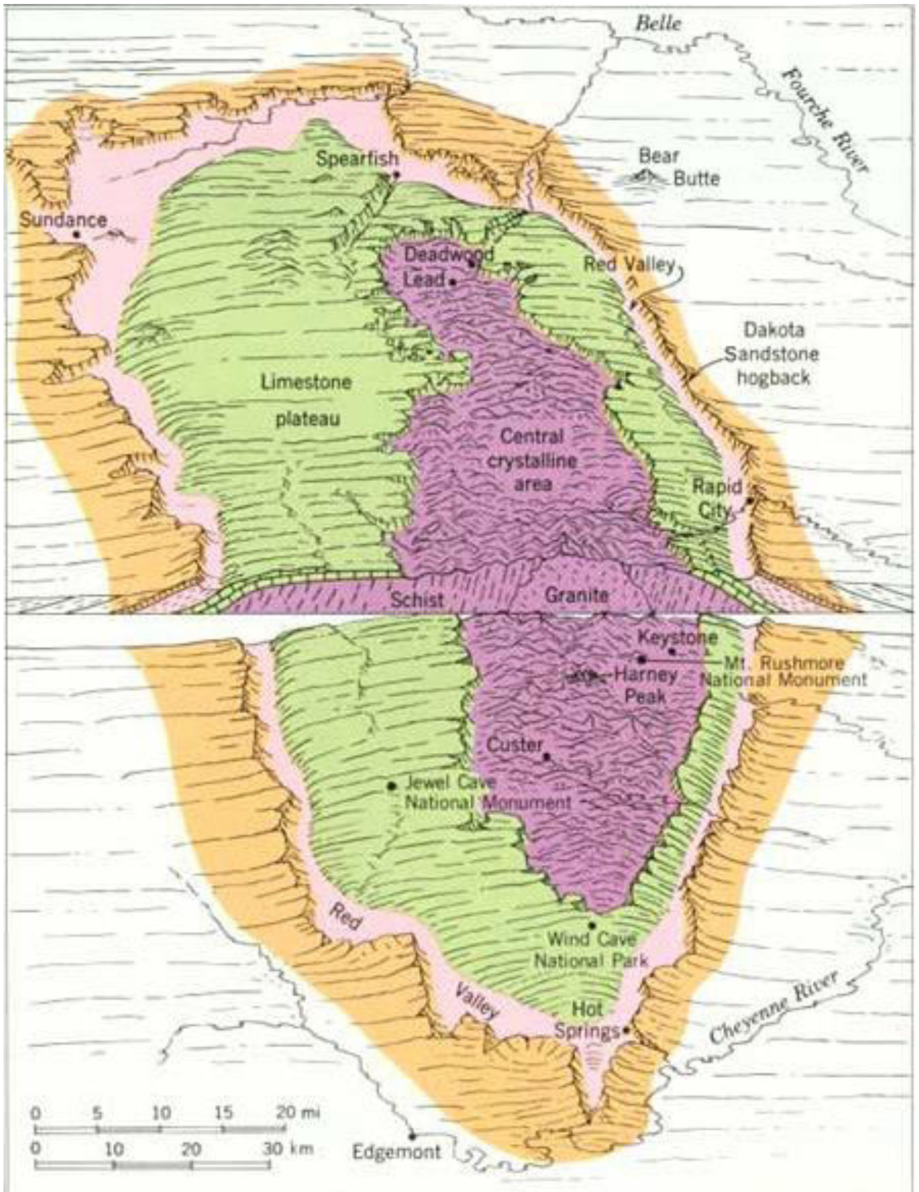

Figure 3.18. *Diagram of the Black Hills uplift. Precambrian-aged granites and metamorphic rocks make up the core of the Black Hills (purple). Early-Paleozoic marine sequences (limestones) (green), late-Paleozoic/Mesozoic red clastics (pink), and Cretaceous-aged clastics (orange) dip away from the core in concentric-rings around the dome. Figure 10 from Trimble (1980).*

Like the formations of the Rocky Mountain physiographic provinces discussed previously, these formations are composed of red, siliclastic sedimentary rocks (shales, sandstones, siltstones) deposited from contemporary mountain and upland sources in fluvial, deltaic, and eolian environments as the region shifted out of a marginal-marine environment in the late-Permian and alternated between a variety of terrestrial environments throughout the Triassic and Jurassic periods (Robinson et al., 1964; Lisenbee, 1988). Formations found in this "Red Valley" include the Spearfish, Sundance, Gypsum Springs, Morrison, Chugwater, and similar formations (Robinson et al., 1964; Lisenbee, 1988) (Table 3.26).

The Black Hills: F21 – Red Parent Material User Notes

PRPM soils in the Black Hills areas (Table 3.28) occur as residual, colluvial, and alluvial deposits in close association with the red bed formations that characterize the "Red Valley." Similar to the soils of the Middle and Southern Rockies, characteristics of the soils in the Black Hills are dependent upon the characteristics of their parent formations. Generally, most soils are loamy to silty in texture, and calcareous and/or gypsiferous as the red bed deposits in this region are heavily interbedded with marine and evaporite rocks deposited with the red beds in the late-Permian period and Mesozoic era. Residual soils derived directly from bedrock are shallow, and occur on upland landscape positions such as ridges, and convex hillslopes of uplands (e.g. Gypnevee, Rekop, Spearfish, and similar soils). Likewise, alluvial and colluvial deposits tend to be more stratified, contain more rock fragment (gravels, cobbles, etc.) are occur on lower landscape positions that grade out of upland areas or are associated with active river/stream networks such as alluvial fans, backslopes, terraces, and valley fills (e.g. Barnum, Gystrum, Nevee, Swint, Thermopolis, Vale, and similar soils). Also, like the soils of the Middle and Southern Rockies, PRPM soils of the "Red Valley" can be mixed with materials weathered from other bedrock sources uplifted from the Laramide orogeny (Precambrian granites/schists and Paleozoic-aged rocks weathered from areas of higher elevation).

Many of the red beds that derive problematic RPM are also associated with the occurrence of marine sequences and evaporites (limestones, dolomites, gypsum, etc. not recognized as problematic RPM) also deposited during the Permian to late-Jurassic periods, and therefore knowledge on the characteristics of the red bed formations is also important when making F21 hydric soil determinations in these areas. CCPI data to confirm PRPM soils is also lacking in many areas where red bed formations are known to occur. For these reasons, additional CCPI analyses may be helpful to confirm F21 hydric soil determinations in these areas.

The Arizona and New Mexico Mountains

The last division of the Western Mountains and Basins sub-region where problematic RPM is possible to occur is generally defined as the mountainous terrain and surrounding basins that occur within the states of New Mexico and Arizona, roughly equal the areas within and surrounding the USDA-NRCS MLRA 39 – the Arizona and New Mexico Mountains (Figure 3.17, A) (USDA-NRCS, 2006). In NM, this division includes all mountain ranges and basins that bound the Rio Grande Rift that cuts through the center of the state, as well as the mountains and basins associated with the Mogollon Rim that cuts east to west across central AZ and western NM. Of these ranges include: the southern Sangre de Cristo Mountains, Tusas Mountains, and Jemez mountains in northern NM (Santa Fe, NM area);[88] the Manzano, San Pedro, and surrounding mountains in central NM (Albuquerque, NM area); the Sacramento Mountains in southern NM (north of the NM-Mexico border); and the Datil-Mogollon Mountains that trend east to west across the states of AZ and

[88] These mountain ranges overlap/transition with that of the Southern Rocky Mountain physiographic province discussed previously (see "*The Middle and Southern Rocky Mountains*" section for more information).

NM (Figure 3.17, A). Like the Rocky Mountain and Black Hills areas discussed previously, the red bed formations that derive problematic RPM in these areas were also deposited from contemporary mountain and upland sources in fluvial, deltaic, and eolian environments as the region shifted out of a marginal-marine environment in the late-Permian and alternated between a variety of terrestrial environments throughout the Triassic and Jurassic periods (Lee and Girty, 1909; Atkinson, 1961; Clark, 1966; Pray, 1961; Huddle and Dobrovolny, 1952) (Table 3.26).

It should be also noted that some of these Permian and Mesozoic red beds (e.g. the Manzano Group: Abo, Yeso, etc. formations) have been recognized as problematic RPM along the northern reaches of the Rio Grande Rift just south of the Colorado Plateau physiographic province in the San Juan Basin in central NM (Lee and Girty, 1909; Darton, 1928) (Figure 3.17, A). This river itself runs from headwaters in the Southern Rockies in CO, and then north-south across central NM through a series of interconnected grabens (down-dropped fault blocks that form a rift valley) formed during an extension and collapse of the North American between the last 35 and 29 Mya (Keller and Baldridge, 1999). The geology of the rift valley is mostly composed of exposed weathering-resistant, Precambrian basement rocks (granites), recent (Cenozoic) volcanic flows, and sedimentary fill derived from nearby alluvial fan and volcanic sources from upland sources that surround the rift valley (Keller and Baldridge, 1999). These parent materials are not recognized as problematic RPM, however, the red beds exposed along certain parts of the rift are possible sources of problematic RPM in the Desert Southwest and Western Mountains region (Figure 3.17, A). The river eventually travels through the Big Bend area of southwestern TX to the TX and Mexico border in USDA-MLRA 42, however, alluvial deposits of the river as associated with these red beds that occur along the rift have yet to be confirmed as problematic RPM (via CCPI analyses). Additional data collection may aid in further constraining the extent of problematic RPM in these areas.

The Arizona and New Mexico Mountains: F21 – Red Parent Material User Notes

Soils derived from problematic RPM in the areas defined in the Arizona and New Mexico Mountains (Table 3.28) are poorly understood, as very few soil samples were collected and analyzed for CCPI from these areas from project collaborators. Where problematic RPM is recognized, deposits are of an alluvial origin, occurring on alluvial fans that transition out of mountainous regions that transition with the Colorado Plateaus (Grand Canyon and Datil sections) and Southern Rocky Mountains (Sangre de Cristo, Jemez, etc. Mountains); and/or as mixed alluvial deposits along the floodplains of the Rio Grande River (e.g. Peralta, Palma, and similar soils). Specially, in areas of the San Juan Basin and along the Rio Grande Rift, soils are heavily mixed with volcanic rocks not considered to be problematic RPM. Most of the problematic RPM identified in guidance maps for these areas in the Desert Southwest and Western Mountains region (Figure 3.17, A) are geological map units (correlated with problematic RPM identified in other nearby areas - Southern Rockies, Colorado Plateaus, etc.), and additional CCPI data may further constrain PRPM soils to areas where these red bed formations are known to outcrop/occur. For these reasons, additional CCPI analyses may be helpful to confirm F21 hydric soil determinations in these areas.

Colorado Plateaus

Problematic RPM of this group belong to a collection of soils and red bed formations found within the Colorado Plateaus physiographic province, roughly centered in the "Four Corners Region" of the southwestern U.S. (southeastern UT, northwestern AZ, southwestern CO, and northeastern NM) (Figure 3.17, A). This area includes all RPM found within the six geographic sections that compose the Colorado Plateaus physiographic province: the Uinta Basin, High Plateaus, Grand Canyon, Canyon Lands, Navajo, and Datil sections (Figure 3.19).

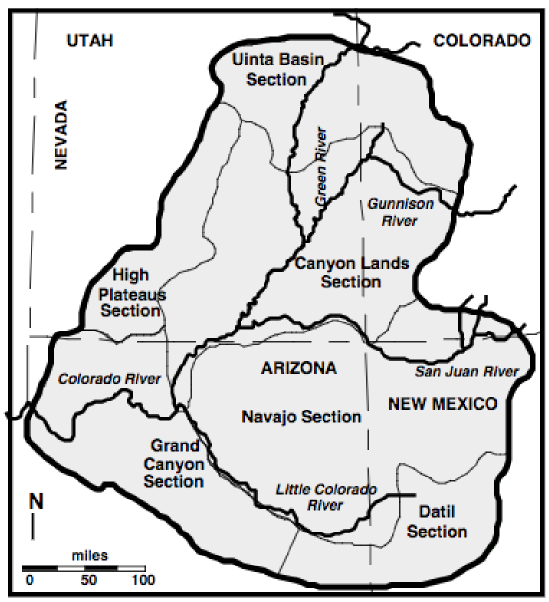

Figure 3.19. *Map of the Colorado Plateaus physiographic province showing its six section boundaries. The Colorado Plateaus province is bound by the Uinta Mountains of Utah and the Southern Rocky Mountains in CO to the northeast and northwest, the Rio Grande Rift Valley in NM to the east, and the Mogollon Rim in AZ to the south. The Plateau is drained and generally divided by major tributaries of the larger Colorado river. Figure 1 from Foos (1999), after Figure 1 from Hunt (1956).*

The Plateau, itself, is a high standing crustal block of relatively undeformed rocks, broadly folded and exposed in a series of plateaus that have been relatively structurally unchanged for the last 600 My (Hunt, 1956; Fillmore, 2011). The plateaus are separated by north-south trending faults or monoclines formed from the movement of Precambrian (Proterozoic) rocks that make up the basement complex of the Plateau. Throughout the Paleozoic era, the Plateau region was periodically submerged by tropical seas, resulting in the deposition of carbonate and siliclastic sequences in both deep and shallow marine water environments that buried the Precambrian basement rocks (Hunt, 1956; Fillmore, 2011). In the late Paleozoic to early Mesozoic (Pennsylvanian through Triassic), basement faults in the North American plate were reactivated to form the Ancestral Rocky Mountains, broad uplifts, and a series of sedimentary basins. During and following the formation of the supercontinent of Pangea (~250 Mya), marine deposition waned and terrestrial deposits dominated in the area. Several orogenies, initiated on the west coast (e.g. Nevadan, Sevier, etc.), resulted in the formation of volcanic rocks along the orogenic belts, and highlands that shed large volumes of sediment into the Colorado Plateau area (Hunt, 1956; Fillmore, 2011). During the late Cretaceous-early Tertiary periods, the Laramide orogeny occurred to form the current (Rocky) mountain systems that bound the Plateau to the north and east, and resulted in the gentle deformation (i.e. normal and monocline faulting) of the deposits in the Plateau (Hunt, 1956; Fillmore, 2011). Recent uplift of the entire Rocky Mountain system and Colorado Plateau over the last ~5 My, and the evolution of the Colorado river over the last 70 My, have sculpted the deeply incised canyons and landscapes that currently characterizes the Colorado Plateau province today (Rigby, 1977).

Regarding problematic RPM, however, the source rocks that produce PRPM soils in the Colorado Plateaus are generally restricted to red bed formations deposited between the late-Pennsylvanian to late-Jurassic periods, when terrestrial deposition of sediments (weathered/sourced from the Ancestral Rockies and other orogenic belts) dominated in the region. Similar to the sediments described for the Rocky Mountains discussed previously, the source rocks of problematic RPM in the Colorado Plateaus, dated from these time periods, are interpreted to be deposited in the region's contemporary basins as marginal-marine/deltaic environments (Permian) and a variety of terrestrial-fluvial (rivers, streams, lakes, etc.) (Triassic and Jurassic) as the region transitioned from under a shallow sea into a tropical monsoonal and aridic-desert climate (Fillmore, 2011). Some formations of this sub-region that represent the environments of the late-Pennsylvanian to the late-Permian periods are the members/formations of the Supai Group (McKee, 1975), Hermit Shale (Duffield, 1985), and Culter Group (Condon, 1997). These formations are typically interbedded sequences of bluff-to-red colored sandstones (arkose), siltstones, shales, and carbonate rocks (limestones, dolomites, etc.), indicative of oscillating transgressions and regressions of sea level where sediments were deposited in near-shoreline, offshore, and shallow marine environments. As the sea retreated into the late-Permian, early-Mesozoic era, red sediments (sourced from upland sources) became deposited by rivers, streams, etc. in supratidal, forested environments (Fillmore, 2011).

From the late-Triassic to mid-Jurassic period, however, much of this area that is now the Colorado Plateaus specifically fluctuated between a temperate climate (fluvial-lacustrine environment) and an aridic climate (eolian environment similar to that of the today's current Sahara Desert) (Fillmore, 2011). Groups of strata (known to contain red bed sequences) dated between these time periods are therefore sometimes heavily interbedded with red- to bluff-colored, cross-bedded sandstones indicative of large dune and interdune deposits that once blanketed the region. These deposits are represented by formations/members of the Glen Canyon group (Wingate, Navajo Sandstone, etc.) (Freeman, 1976), as well as members of the San Rafael Group (Entrada Sandstone) (Anderson et al., 1997) (Table 3.26). Formations deposited prior and following these time periods (from the early-Permian to late-Triassic, and from the mid-to-late Jurassic), are dominated more by fluvial-deposits, particularly of lacustrine origin that exhibit a characteristic stacking pattern as lake basins fill (Demko et al., 2005). These fluvial and lacustrine deposits are represented by the Morrison, Chinle, and Moenkopi formations (Stewart et al., 1972; Demko et al., 2005) (Table 3.26).[89]

Overall, each of the red bed formations, or their equivalent correlated formations, occur throughout all sections of the Colorado Plateaus. Generally, however, the late-Pennsylvanian- to Permian-aged red beds tend to dominate/occur more in the Grand Canyon section of the Colorado Plateau, while the other sections (Datil, Navajo, Canyonlands, etc.) are dominated more by the fluvial and eolian red bed deposits of the Mesozoic era (Figure 3.19; Foos, 1999). The Grand Canyon section of the Plateau is also known to preserve a variety of red bed sequences deposited during the Precambrian time (i.e. Nankoweap Formation of the Grand Canyon Supergroup; Table 3.26) (Elston and Robert Scott, 1973; Elston, 1993), and possibly a variety of other red bed sequences associated with the Paleozoic era that

[89] These Triassic and Jurassic formations are lithologically correlated to those that occur in the Tucumcari Basin of the upper Pecos River Valley (See "*Pecos River Valley*" section of this chapter). In comparison to the Mesozoic deposits of the Pecos River Valley, the beds in the Colorado Plateaus generally preserve a larger amount/thickness of the eolian members deposited during these time periods.

may produce PRPM soils in these areas as well.[90] Additional data collection and CCPI analyses may help further constrain the distribution of problematic RPM in association with these red beds dated from the Precambrian and Palezoic era. Finally, while no soil samples (CCPI analyses) were provided in this context, it is also possible that Quaternary-aged alluvial deposits along the tributaries and river channels of the larger Colorado river system (that drains the majority of the Colorado Plateau) also likely produces PRPM soils in and around this sub-region. Additional data collection and CCPI analyses of soils would help to better constrain the occurrence and distribution of problematic RPM in this sub-region overall.

The distribution of problematic RPM and their associated soils within the Colorado Plateaus province are shown in RPM guidance maps for the Desert Southwest and Western Mountains region (Figure 3.17, A). Table 3.29 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM occurs as associated with the Colorado Plateaus.

Table 3.29. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Colorado Plateaus.*

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Arid West	D – Western and Irrigated Region	34A – Cool Central Desertic Basins and Plateaus 34B – Warm Central Desertic Basins and Plateaus 35 – Colorado Plateau 36 – Southwest Plateaus, Mesas, and Foothills
Western Mountains, Valleys, and Coast	D - Western and Irrigated Region	39 – Arizona and New Mexico Mountains
	E – Rocky Mountain Range and Forest Region	47 – Wasatch and Uinta Mountains 48A – Southern Rocky Mountains

**Note - this table reflects all USDA-NRCS LRRs and MLRAs where portions of its area are contained within the Colorado Plateaus physiographic province. USDA-NRCS MLRAs 39 and 47 transition between many of the mountainous areas defined within the "Western Mountains and Basins" section of this chapter.*

[90] Other Precambrian and Paleozoic-aged red beds may also be possible in a variety of further uplifted areas contained within the Colorado Plateaus province, including, but not limited to: the San Andres (Kottlowski, 1955), Zuni (Armstrong et al., 1994), Nacimientos (Spencer and Heckert, 1996), Defiance Uplift, and Chuska Mountains (Blagbrough, 1967).

Table 3.30 lists the soil series identified as potential problematic RPM (included in RPM guidance maps) that are associated with the Colorado Plateaus. See Table 3.26 for the list of potential geological formations that can derive these soils.

Table 3.30. Soil series identified as potential problematic RPM that are associated with the Colorado Plateaus.

Soil Series					
Acree	Epikom	Mack	Monue	Remorris	Tobler
Aneth	Fortwingate	Mellenthin	Naplene	Ribera	Tours
Arches	Gladel	Mespun	Nuffel	Rizno	Wetherill
Arntz	Grassytrail	Mido	Padilla	Robroost	Whitecanyon
Barx	Hadden	Milok	Palma	Sandark	Winkel
Begay	Hagerman	Mivida	Parkelei	Schmutz	Yahmore
Blackston	Hassell	Moenkopie	Penzance	Simel	
Brinkerhoff	Hillburn	Mokaac	Plome	Strych	
Burnswick	Jocity	Monogram	Redbank	Suwanee	
Caval	Leanto	Monticello	Regracic	Tintero	

Colorado Plateaus: F21 – Red Parent Material User Notes

While the Colorado Plateau is divided into six physiographic sections, the surface of the sub-region is characterized by gently to strongly sloping plains interrupted by volcanic plugs, steep scarps, plateaus, and deeply incised canyons (USDA-NRCS, 2006).[91] PRPM soils occur as residual, colluvial, eolian, and alluvial deposits throughout this landscape.

Generally, much of the soil surface of the sub-region is considered to be of an alluvial origin where sediments have been weathered from exposed bedrock in upland sources and washed downward into lower valleys, etc. throughout the Cenozoic era under an aridic climate. Therefore, most of the PRPM soils of this sub-region is of this alluvial origin. Throughout the area, these alluvial deposits derived from problematic RPM can occur on a variety of geomorphological landforms, including but not limited to alluvial fans/fan terraces, cuestas, hogbacks, pediments, mesas,

[91] For more information on the (geological, geographical, etc.) features of the six physiographic sections of the Colorado Plateaus province, see Hunt (1956); Rigby (1977); amongst others.

structural benches, etc. as valley fill, slope alluvium, etc. (e.g. Barx, Epikom, Moenkopie, Suwanee, Parkelei and similar soils). Specific characteristics of these alluvial deposits (texture, structures, etc.) are dependent upon the lithological characteristics of the parent bedrock (sandy if derived from sandstone, silty if derived from siltstones, etc.), but are more active/smectitic in their mineralogy if derived from finer-grained rocks such as shales and mudstones. It is also very common for these alluvial deposits to be shallow/underlain by bedrock (occurring within ~30-50 cm) that may or may not be problematic RPM as well (e.g. Blackston, Epikom, Gladel, Hadden, and similar soils). Some PRPM soils are also mapped/occur in association with the current drainage/river systems of the Colorado Plateau (i.e. tributaries/main channel of the Colorado River) (e.g. Jocity, Mack, Nuffel, Suwanne, and similar soils). These soils tend to occur on more recent floodplains, and active, low stream terraces on valley floors, in comparison to the other alluvial deposits transported by water in areas with a higher relative elevation.

Eolian deposits derived from problematic RPM throughout much of this sub-region tend to be sandy in texture, siliceous, and mostly occur in association with sandstone formations (those deposited during times in the Triassic/Jurassic periods when the Colorado Plateau was similar to an environment that resembles the current Sahara Desert). These soils can occur on a variety of landforms similar to the alluvial deposits, in addition to upland valleys, on tops of escarpments, stabilized dunes, and sand sheets (e.g. Aneth, Leanto, Arches, Mespun, Wetherill, and similar soils). Many PRPM soils are also a mixture of both eolian and alluvial sources and are also commonly underlain by bedrock that may or may not be problematic RPM. Soils that are a mixture of both eolian and alluvial materials tend to be more stratified and are more loamy than sandy in texture (e.g. Ribera, Robroost, and similar soils).

PRPM soils derived directly from residuum of problematic RPM and/or their eolian members are represented by the Arches, Gladel, Remorris, Rizno, Simel, and similar soils. Colluvial soils derived from problematic RPM tend to have high amounts of rock fragment (stony, cobbly, flaggy, etc.), and occur on landforms (similar to the eolian and alluvial deposits) that are more steeply sloping. These are represented by the Hillburn, Mellenthin, Milok, and similar soils. It is not uncommon for residual and colluvial PRPM soils to be blanketed with additional eolian and alluvial materials that may or may not be problematic RPM.

Throughout the entire sub-region, all of these PRPM soils are calcareous (at depth), containing calcium carbonate as masses or concretions. Many are gypsiferous, and some are even natric/sodic (e.g. Burnswick, Penzance, and similar soils). Some RPM soils are also mapped in association with mountain ranges/recent uplifts (Southern Rockies, Wasatch and Uinta Mountains, etc.), that occur within and/or mark the boundaries of the Colorado Plateaus physiographic province (e.g. Acree, Monticello, Plome, Redbank, Sandark, Yahmore and similar soils). These soils are typically mixed with materials sourced from a variety of other rocks that are not problematic RPM (basaltic flows, volcanic ash, Cretaceous-aged sedimentary rocks, etc.), and occur at higher elevations compared to the elevation within the Colorado Plateau. As a result, these soils tend to possess characteristics that do not necessarily reflect a dry, aridic climate characteristic of much of the Colorado Plateau (i.e. dark-surface horizons similar to prairie soils), as the climate of the Plateau shifts from dry/arid to wetter/cooler towards more mountainous/uplifted areas.

Overall, all PRPM soils (residual, eolian, alluvial) throughout this sub-region can be mixed with a variety of materials sourced from other rocks that are not recognized as problematic RPM (such as igneous and volcanic rocks located mostly around the margins of the Colorado Plateau [Hunt (1956)], or limestone members of Permian formations that contain red bed sequences, etc.). Many of the areas associated with the geological formations identified as problematic RPM (Table 3.26), and those possibly correlated to them, in this Colorado Plateau sub-region lack CCPI data to confirm the presence of PRPM soils in association with them throughout their entire distribution as well. For these reasons, it is recommended that additional CCPI analyses be collected when making F21 hydric soil determinations in these areas in all cases.

Finally, although problematic RPM and their associated soils are very extensive in the Colorado Plateau, much of the area has a relatively dry climate that falls within the aridic soil moisture regime.[92] Therefore, while many of the parent materials and associated soils meet CCPI requirements of the F21 – Red Parent Material field indicator, it is not expected that extensive areas of hydric soils occur throughout the region. Nevertheless, red beds in the Colorado Plateau of the greater Four Corners Region (Table 3.26) are known to be the source rocks of PRPM soils in this region, as well as some possible other soils associated with the region's watersheds outside the boundaries of the Colorado Plateau (i.e. the Colorado River

[92] The aridic moisture regime, generally, reflects a soil moisture balance where the annual precipitation is less than the potential evapotranspiration. For more information on the definitions and concepts of soil moisture regimes, refer to Soil Survey Staff, USDA-NRCS (2014).

system). As a result, the F21 – Red Parent Material may be useful in identifying hydric soils in landscape positions where water accumulates and wetlands are likely to occur (USACE, 2010b). Additional data collection and CCPI analyses of soils would help to better constrain the occurrence and distribution of problematic RPM throughout the Colorado Plateaus physiographic province.

The Pecos River Valley (Tucumcari and Delaware Basins)

Problematic RPM of this group belong to a collection of red beds that outcrop north to south across central NM, in northeastern parts of the TX Panhandle, and in parts of southwestern TX associated with the Pecos River Valley (MLRA 70B) (Figure 3.17, A and C). Like much of this RPM region, the sediments that produced these red beds in the Pecos River Valley were predominantly laid down in a variety of depositional environments during the late-Pennsylvanian to late-Jurassic periods. Generally, in this sub-region, the red beds dated from the late-Pennsylvanian to late-Permian periods are understood to be deposited in a series of basins and paleo-continental shelves of the "Greater Permian Basin" (Figure 3.16) in marginal-marine and deltaic-type environments related to the transgressions and regressions of an ancient ocean that once submerged the basins from the south (Lang, 1937; Silver and Todd, 1969). In conjunction, the Mesozoic beds dated from the Triassic and Jurassic periods are understood to be deposited in a variety of terrestrial-eolian and terrestrial-fluvial environments of low-, medium-, and high-energies (lakes, meandering streams, large rivers, etc.) that carried eroded sediments from nearby upland sources (e.g. the Ouachita, Marathon, Ancestral Rocky mountains, etc.) towards the basin as the basins filled with sediments and sea levels receded (Lucas et al., 2001; Mankin, 1972). Many of the Permian red beds are lithologically correlated to strata confirmed as problematic RPM in north-central TX, central OK, and southern KS (see the "*South-Central*" and "*Central Red Bed Plains*" sections prior), while the (Mesozoic) red beds are lithologically correlated to those that occur in the Colorado Plateaus and nearby Rocky Mountain systems (see "*Colorado Plateaus"* and "*Western Mountains and Basins*" sections prior). The problematic RPM of this sub-region is limited to red bed strata exposed within the Tucumcari basin in central NM (Figure 3.20), as well as the southern Midland, Central Platform, and Delaware Basins in central NM and southwestern TX (Figure 3.21).

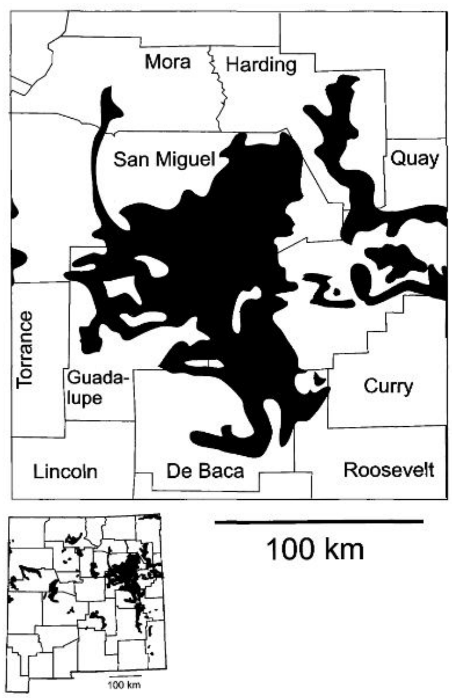

Figure 3.20. *Outcrops of Triassic strata in the generalized location of the Tucumcari Basin in central NM (A). Outcropping Triassic and Permian red beds recognized as problematic RPM extend from this basin north-south across central NM (B). Straight, solid lines represent NM county borders. Figure 1 from Lucas et al. (2001).*

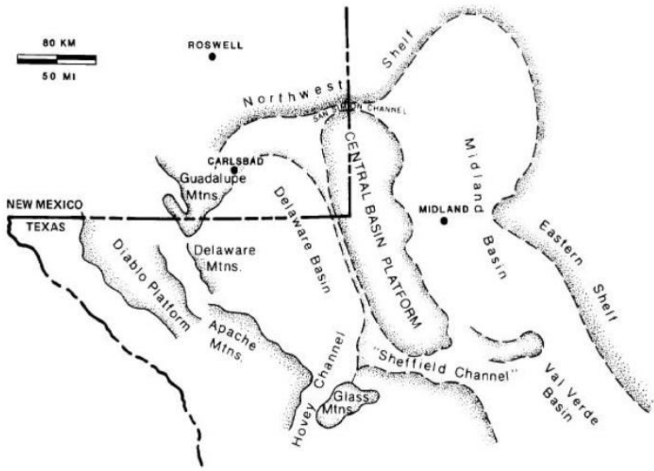

Figure 3.21. *Geographic boundaries of the Midland, Central Platform, and Delaware basins in southeastern NM and southwest TX. The Delaware Basin is bounded by the Guadalupe, Delaware, Apache, and Glass mountains to the south and west. Problematic RPM of the Tucumcari Basin extends into the Northwestern Shelf area across central NM (See Figure 3.20 for comparison). Problematic RPM in the Eastern Shelf areas of central TX are discussed in the "South-Central" and "Central Red Bed Plains" sections of this chapter. Figure 1 from Ward et al. (1986).*

Generally, the Mesozoic red beds of this sub-region characterize the northern parts of the Pecos River Valley (the northern half of the Tucumcari Basin that stretches from northern NM east into the Panhandle of TX), while the Permian formations characterize the more southern parts (the southern half of the Tucumcari Basin from central NM south into the Delaware Basin in southern NM/southwestern TX and southern parts of the Midland Basin and Central Platform in TX) (Lucas and Anderson, 1998; Mankin, 1972; Scholle, 2003) (Figure 3.17, A and C). Some formations identified as problematic RPM in guidance maps for the Desert Southwest and Western Mountains region (Table 3.26, Figure 3.17) that represent the Triassic and Jurassic periods are formations of the Chinle Group, formations of the San Rafael Group (Todilto, Summerville, etc.), and the Morrison formation (Lucas and Anderson, 1998; Mankin, 1972). Some formations identified as problematic RPM in guidance maps for the Desert Southwest and Western Mountains RPM region (Table 3.26, Figure 3.17) that represent the Permian period are the formations of the Artesia

Group, as well as the Abo and Yeso formations (Kelley, 1972). Additional geological formations known to be related and/or similar to these formations (not indicated in Table 3.26) were not included in RPM guidance maps for the Desert Southwest and Western Mountains RPM region as CCPI data was lacking to confirm the presence of problematic RPM in their areas of occurrence.[93]

Like the red beds of the Central Red Beds Plains, the rock sequences known to contain red beds also grade into sequences dominated more by gray, marine-carbonate rocks (limestones, dolomites, evaporites, etc.) that are not recognized as problematic RPM to the south (i.e. the Delaware Basin in southern parts of MLRA 70B, eastern parts of MLRA 42, and westernmost parts of the Western Edwards Plateau in MLRA 81A) (Kerans et al., 1993; Silver and Todd, 1969). Sequences of red beds that produce PRPM soils may be present in these areas dominated by these marine rocks, however, they were not included in RPM guidance maps for the Desert Southwest and Western Mountains RPM region (Figure 3.17, A and C) as no samples (CCPI analyses) were provided to confirm the presence of problematic RPM in their areas of occurrence. Much of the (late) Permian-aged (Guadalupian) strata, and perhaps some older Paleozoic-aged (Silurian, Devonian, Mississippian, and Pennsylvanian) formations known to contain red bed sequences, may also be exposed in uplifted outcrops in the Guadalupe, Delaware, Apache, and Glass mountains that surround the Delaware Basin (see Boyd, 1958; Hill, 2006) (Figure 3.21). These

[93] Some additional formations that may be problematic RPM from the Permian period in these areas are the San Andres (Kelley, 1972), Brushy Canyon (Beaubouef et al., 1999), Rustler (Boghici and Van Broekhoven, 2001), Dewey Lake (Molina-Garza et al., 1989), Salado (Johnson, 1993), and similar formations. Some additional formations that may be problematic RPM from the Mesozoic era are formations/members of the Dockum Group and similar formations, found predominantly within the northern panhandle and southwestern areas of TX (Gould, 1906; McGowen et al., 1977).

formations were not included in RPM guidance maps for the Desert Southwest and Western Mountains RPM region (Figure 3.17, A and C) as no soil samples were provided to confirm the presence of problematic RPM (via CCPI analyses) from these areas.

The Lower Pecos River

Furthermore, like the Arkansas, Brazos, Red, etc. rivers discussed in the South-Central RPM region (see "*Central Red Bed Plains Alluvium*" sections prior), a variety of river systems drain these areas characterized by red beds within or associated with the Upper Pecos River Valley. Notably, the Pecos River flows north-south across central NM that is dominated by the red bed formations that produce problematic RPM (Figure 3.17, A), and therefore, Quaternary-aged alluvial deposits along (downstream) parts of the Pecos River watershed also likely derive PRPM soils (Figure 3.17, C). Tributaries of the river originate in northeastern NM in a north-south canyon dominated by Pennsylvanian-aged limestones (not recognized as problematic RPM) on the eastern slope of south end of the Sangre de Cristo mountain range (a range that is part of the Southern Rocky Mountains, MLRA 48A) (Gregory and Halter, 2008; Noble, 1993; Herron, 1916). From here, the river encounters a low spur of the Sangre de Cristo mountains and the Glorieta Mesa where it's river valley begins over exposed Permian-aged, red/maroon-colored shales of the Sangre de Cristo formation on the east side of the base of the mountain range (Gregory and Halter, 2008; Noble, 1993) (MLRAs 48A, 49).[94] The river then cuts eastward into an entrenched valley curving around the Tecolote mountain range (created by an

[94] No soil samples (CCPI analyses) were collected from these areas, thus, these areas associated with the Pecos River in the Sangre de Cristo mountains were not included in RPM guidance maps (Figure 3.21, A and C).

anticlinal fold in erosion-resistant Pennsylvanian- and Permian-aged bedrock), and flows southward along the western flanks of the range (Noble, 1993) (USDA-MLRAs 70A/B/C/D). Here, the river cuts into areas characterized by the red, Permian and Mesozoic sediments (confirmed as problematic RPM, see Table 3.26) exposed at the surface. Upon reaching Carlsbad and the Guadalupe Mountains in southern NM, the Pecos River enters the Delaware Basin (a basin dominated by gray, marine sequences [limestones, dolomites, etc.]) and into southwestern TX (MLRA 42) (Figure 3.22).

Figure 3.22. *Course of the Pecos River through the Delaware Basin in southwestern, TX.*

Exiting the Delaware Basin in west TX, the river enters and flows across the western and southern parts of the Edward's Plateau (MLRAs 81A/D) before joining the Rio Grande as its final tributary on the easternmost edge of the Big Bend area of TX at the TX and Mexico border (Gregory and Halter, 2008).[95] In these areas of the Edward's Plateau, the river flows across landscapes characterized primarily by limestones of Cretaceous age (USDA-NRCS, 2006) that are not recognized as problematic RPM, however, alluvial sediments deposited by the Pecos River in the

[95] The Pecos joins the Rio Grande on the TX and Mexico border near the U.S. 90 - Pecos Bridge Rest Area in Val Verde County, TX.

river valleys in these lower stretches of its watershed can likely produce PRPM soils sourced from the Mesozoic and Permian red beds in central NM/southwestern TX. These river deposits were not included in RPM guidance maps for the Desert Southwest and Rocky Mountain region (Figure 3.17, A and C) as no soil samples were provided to confirm the presence of problematic RPM (via CCPI analyses) from these areas. Additional data collection and CCPI analyses of soils would help to better constrain the occurrence and distribution of problematic RPM in the Pecos River and in lower stretches of the Pecos River Valley. Therefore, CCPI analyses may be helpful to confirm F21 - RPM hydric soil determinations in these areas.

Upper Canadian and Cimarron Rivers

Furthermore, in addition to the Pecos River, both the Canadian and Cimarron rivers have headwater streams that flow across red beds correlated to those identified as problematic RPM in the Upper Pecos River Valley (Table 3.26), particularly the Triassic and Jurassic beds that characterize northeastern NM. Similarly to the Pecos River, the Canadian rises on the east side of the Sangre de Cristo mountains in northeastern NM and flows southward across the plains of Las Vegas, NM, cutting a deep gorge into the Canadian escarpment.[96] From here, the Canadian river cuts eastward in a narrow valley/channel down-cut into Triassic and Jurassic (sandstones)

[96] In this part of its watershed, the Canadian River has a large tributary also known as the Cimarron River. This tributary is separate from the Cimarron River that flows across the South-Central RPM region, is entirely within New Mexico, and drains areas from its headwaters in the Sangre de Cristo mountains into the Canadian River where the two rivers meet in Springer, NM. The upper stretches of the Canadian River contain or are somewhat characterized by Permian, Triassic and Jurassic red beds that outcrop on the eastward side of the Sangre de Cristo mountains and within the Las Vegas plains in northeastern NM (Lessard and Bejnar, 1976; Mankin, 1972), while its Cimarron tributary drains an area dominated mostly by sediments dated from the Cretaceous to the Quaternary periods that are not recognized as problematic RPM (Thomson and Ali, 2010). These areas are not included in RPM guidance maps for the Desert Southwest and Western Mountains RPM region (Figure 3.17, A) as no soil samples (CCPI analyses) were provided from these areas.

and Permian red beds across the northwestern parts of the TX panhandle, known as the "Canadian Breaks" (National Park Service, 2017; Bureau of Economic Geology, 1996) (USDA-MLRAs 70A/B). The Canadian River then flows across the northeastern parts of the TX Panhandle in a landscape characterized by loamy to sandy sediments of the Ogallala formation (MLRA 77E) (USDA-NRCS, 2006) that are not recognized by as problematic RPM before entering the Central Rolling Red Prairies (MLRA 78C) where the underlying geology is again problematic RPM of Permian age.[97] These Permian, Triassic, and Jurassic red beds, and recent alluvial deposits of the upper Canadian River across these drainage areas are likely problematic RPM, however, no soil samples (CCPI analyses) were provided from these areas, and thus caution and CCPI analyses of soils are recommended when making F21 hydric soil determinations in these areas.

Likewise, the Cimarron River rises from headwater streams in northeastern New Mexico (MLRA 70A) in an area known as the Dry Cimarron Valley (in MLRAs 77A/B). Here, Jurassic strata of the Chinle group (recognized as problematic RPM, Table 3.26) are exposed in canyons carved by the river (Anthony, 1955; Lucas et al., 1987). Sediments from these exposed red beds are therefore possibly transported by the Cimarron River into lower portions of its watershed and deposited as recent, Quaternary-aged alluvial deposits. From this valley, the river enters the westernmost

[97] These Permian red beds of the Central Rolling Red Plains (USDA-NRCS MLRAs 78B/C) and the remaining parts of the Canadian River's watershed are further discussed in the "*South-Central*" RPM region of this chapter. See the "*Central Red Bed Plains*" and "*Central Red Bed Plains Alluvium: Arkansas and Red Rivers*" sections for more information. Some RPM soils, predominantly associated with the Central Red Bed Plains area in the South-Central RPM region (Table 3.19), are mapped as alluvium along the upper stretches of the Canadian river in parts of the OK and TX Panhandle, and northeastern NM (e.g. Burson, Clairemont, Colorado, and similar soils in MLRAs 70A/B, and 77A/B/E) (Figure 3.15). Additional CCPI analyses may aid in further constraining the extent of problematic RPM in these areas.

areas of the OK Panhandle, into southern KS, and then back into OK across areas characterized by eolian loess/sand deposits of Holocene age and/or loamy to sandy sediments of the Ogallala formation (MLRAs 77A/E) (USDA-NRCS, 2006). These deposits along its stretch of the watershed are not recognized as problematic RPM. The river then enters the Central Rolling Red Prairies (MLRA 78C) where the underlying geology is again problematic RPM of Permian age.[98] The Jurassic red beds in the Dry Cimarron Valley, and recent alluvial deposits of the upper Cimarron River across these drainage areas may produce PRPM soils, however, no soil samples (CCPI analyses) were provided, and thus, these drainage areas of the Cimarron river were not included in RPM guidance maps for the Desert Southwest and Western Mountains region (Figure 3.17, A). Caution and CCPI analyses of soils are recommended when making F21 hydric soil determinations in these areas.

Finally, while these red bed formations and river systems associated with the Pecos River Valley share similar characteristics and landscape patterns as many of the areas in the South-Central RPM region of this chapter, these areas were included in the Desert Southwest and Western Mountains RPM region of this chapter for a number of reasons. First, many of the Triassic and Jurassic formations that characterize the northern parts of the Pecos River Valley share similar nomenclature/are correlated to formations that occur in more western and mountainous regions of the U.S. in AZ, CO, and UT (see the "*Colorado Plateaus*" and "*Western Mountains and Basins*" sections of this chapter). These formations are

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[98] These Permian red beds of the Central Rolling Red Plains (USDA-NRCS MLRAs 78B/C) and the remaining parts of the Cimarron River's watershed are further discussed in the "*South-Central*" RPM region of this chapter. See "*Central Red Bed Plains*" and "*Central Red Bed Plains Alluvium: Arkansas and Red Rivers*" sections for more information. Additional CCPI analyses may aid in further constraining the extent of problematic RPM in these areas.

largely missing from the Permian areas in central TX, OK, etc. Second, the Pecos River Valley, compared to the areas in the South-Central region, is a landscape characterized with more topographic variability and tectonic activity (from recent uplift and the formation of a variety of mountain ranges in nearby areas). This, and a more aridic climate compared to the Permian areas in the South-Central RPM region, impacts the types of landforms and characteristics of the soils that occur in the area. Third, the river systems that drain these Permian and Mesozoic materials in their associated basins have differing drainage patterns from that of those in the South-Central RPM region. For example, the Pecos River drains to the TX and Mexico border depositing alluvial sediments across the Delaware Basin and sections of Edward's Plateau dominated by Cretaceous-aged, carbonate-marine sequences, not across the Coastal Plain province and into the Gulf of Mexico as wide river systems with broad floodplains underlain by Cretaceous, unconsolidated, marine sediments (i.e. the Arkansas, Red, etc. rivers in the South-Central RPM region). Lastly, there is also a lack of sufficient CCPI data to confirm the occurrence and distribution of problematic RPM in these areas described for the Pecos River Valley and it is recommended that additional CCPI analyses be performed when making F21 hydric soil determinations throughout these areas in all cases.

The distribution of problematic RPM and their associated soils within the Pecos River Valley are shown in RPM guidance maps for the Desert Southwest and Western Mountains region (Figure 3.17, A and C). Table 3.31 indicates the USACE Regional Supplement Regions and USDA-NRCS LRRs and MLRAs where problematic RPM is possible to occur as associated with the Pecos River Valley.

Table 3.31. USACE Regional Supplement Regions and USDA-NRCS Land Resource Regions and Major Land Resource Areas associated with the Pecos River Valley.

USACE Region	Land Resource Region (LRR)	Major Land Resource Area (MLRA)
Arid West	D – Western and Irrigated Region	42 – Southern Desertic Basins, Plains, and Mountains+
Great Plains	G – Western Great Plains and Irrigated Region	70A – Canadian River Plains and Valleys*+ 70B – Upper Pecos River Valley*+ 70C – Central New Mexico Highlands+ 70D – Southern Desert Foothills+
	H – Central Great Plains and Irrigated Region	77A - Southern High Plains, Northern Part* 77B – Southern High Plains, Northwestern Part* 77D – Southern High Plains, Southwestern Part+ 77E – Southern High Plains, Breaks*
	I – Southwest Plateaus and Plains Range and Cotton Region	81A – Edwards Plateau, Western Part+ 81D – Southern Edwards Plateau+
Western Mountains, Valleys, and Coast	E – Rocky Mountain Range and Forest Region	48A – Southern Rocky Mountains* 49 – Southern Rocky Mountain Foothills*

**Note – USDA-MLRAs indicated with a "*" are MLRAs that contain the upper portions of the Canadian and Cimarron Rivers that drain to the Permian red beds in South-Central RPM region. USDA-MLRAs indicated with a "+" are MLRAs that include the lower portions of the Pecos River in southeastern NM and southwestern TX. Problematic RPM may be possible within the entire area of USDA-NRCS MLRA 70B, however, additional data may help to further constrain the problematic RPM distribution within the region.*

Table 3.32 lists the soil series identified as potential problematic RPM (included in RPM guidance maps) that are associated with the Pecos River Valley. Table 3.26 lists some of the possible geological formations that have been identified to produce these soils.

Table 3.32. Soil series identified as potential problematic RPM that are associated with Pecos River Valley.*

Soil Series					
Alama	Glenrio	La Lande	Los Tanos	Quay	San Jon
Bernal	Hagerman	Lacita	Montoya	Redona	Tucumcari
Berwolf	Hassell	Lacoca	Newkirk	Regnier	Tuloso
Conchas	Ima	Largo	Palma	Ribera	Walkon

*Note** **-** *Additional data collection and CCPI analyses may help confirm the occurrence and distribution of problematic RPM in soils associated with this group of problematic RPM.*

Pecos River Valley: F21 – Red Parent Material User Notes

PRPM soils associated with the red beds of the Pecos River Valley sub-region occur as residual, colluvial, eolian, and alluvial deposits throughout the area. Residual soils (mapped as problematic RPM in the northern Tucumcari basin) are typically shallow (30-50 cm) to bedrock, occurring on mesa tops, plateaus, convex ridge crests/ridge slopes/benches, and side slopes of hills and erosional plains (e.g. Bernal, Lacoca, Newkirk, Regnier, Walkon, and similar soils). These soils range from sandy to fine in texture depending on the grain sizes of underlying parent bedrock (as sandstone, siltstone, or shale). Likewise, PRPM soils also occur as colluvial and alluvial deposits on alluvial fans and footslopes washed or eroded from red beds in nearby upland and mountain areas. These soils are typically sandy to loamy, stratified, and can contain some predominant amounts of rock fragment (pebbles, cobbles, stones, etc.) (e.g. Alama, Lacita, Quay, Redona, Tucumcari, Tuloso, and similar soils). To date, no red soils in the Delaware Basin (and its surrounding southern Midland and Central Platform basins) have been confirmed as problematic RPM (via CCPI analyses), despite the known or possible occurrence of red beds correlated to those identified as problematic RPM in South-Central RPM region and the Tucumcari basin to the north.

Furthermore, alluvial PRPM soils in the sub-region typically occur on pediments below escarpments, undulating hills, structural benches, and on channeled valley bottoms along tributaries and the main channel of the Pecos River (e.g. Glenrio, Hassell, Montoya, Los Tanos, San Jon, and similar soils). These soils also range in texture from sandy to fine in texture dependent upon the grain size of the parent bedrock sources of the sediments. Many alluvial soils have eolian materials incorporated into the deposits (have fine sand textures), occurring on undulating plains, dunes of plains, and valley fill side slopes (e.g. Ima, Palma, Ribera, and similar soils). It should also be noted that these alluvial PRPM soils are predominantly mapped in the northern portions of the Pecos River Valley (Tucumcari basin; USDA-NRCS MLRAs 70A/B). Alluvial soils associated with the lower portions of the Pecos River in southern NM and southwestern TX (i.e. Delaware Basin and south) are mapped as clayey deposits on nearly level floodplains of the actual river channel (e.g. Arno, Harkey, Hoban, Patrole, Pecos, and similar soils) (MLRAs 42, 70C/D, 77D), however, these areas were not included in RPM guidance maps for the Desert Southwest and Western Mountains RPM region (Figure 3.17, A and C) as no soil samples were provided to confirm the presence of problematic RPM (via CCPI analyses) from these areas. No soil samples were submitted from the lowermost stretches of the Pecos River in the Edward's Plateau areas of southwestern TX (MLRAs 81A/D) where the river flows to join the Rio Grande at the TX and Mexico border as well.

Amongst all PRPM soils identified in this Pecos River Valley sub-region, all are calcareous, many containing predominant amounts of calcium carbonate as masses and/or concretions. PRPM soils can also be mixed with a variety of other parent material sources including reworked alluvium or eolian materials from Miocene-Pliocene deposits such as the Ogallala formation,[99] volcanic sediments derived from rocks formed from the recent (Cenozoic) uplift of nearby mountains ranges in the area, etc. Additional CCPI analyses are therefore recommended to

[99] This is especially true for PRPM soils that are likely deposited by the upper stretches of the Canadian River that flows from northeastern NM and into the north upper Panhandle of TX (e.g. Glenrio, Quay, San Jon, and similar soils) (MLRAs 70B, 77A/B/E). Some RPM soils derived from recent alluvial deposits along the upper portions of the Canadian and Cimarron Rivers are mapped in guidance maps for the South-Central RPM region in parts of the OK and TX Panhandle, and northeastern NM (e.g. Burson, Clairemont, Colorado, and similar soils in MLRAs 70A/B, and 77A/B/E) (Table 3.19, Figure 3.15 and 3.17, A). Additional CCPI analyses may aid in further constraining the extent of problematic RPM in these areas.

confirm the presence of problematic RPM when making F21 hydric soil determinations in these cases.

Finally, although problematic RPM and their associated soils are extensive in the Pecos River Valley, much of the area has a relatively dry climate that falls within the ustic and aridic soil moisture regimes.[100] Therefore, while many of the parent materials and associated soils may meet CCPI requirements of the F21 – Red Parent Material field indicator, it is not expected that extensive areas of hydric soils occur throughout the region. Nevertheless, these red beds are potential source rocks of RPM soils in this area, as well as other soils that occur in lower portions of the Pecos River watershed. As a result, the F21 – Red Parent Material may be useful in identifying hydric soils in landscape positions where water accumulates and wetlands are likely to occur (USACE, 2010b). Overall, because of a lack in CCPI data to confirm the presence of problematic RPM in these areas associated with the Pecos River Valley, CCPI analyses may help verify F21 hydric soil determinations in the region. Additional data collection may help further constrain the occurrence and distribution of problematic RPM.

Data Limitations, Caveats, and Future Work

Data Limitations and Caveats

Despite the comprehensive approach utilized within this national mapping project, some important data limitations need to be considered when using RPM

[100] The ustic soil moisture regime is an intermediate range between the aridic (drier) and udic (wetter) moisture regimes. The aridic moisture regime, generally, reflects a soil moisture balance where the annual precipitation is less than the potential evapotranspiration. The udic moisture regime, generally, reflects a soil moisture balance in which there is enough seasonal rain so that the amount of stored moisture plus rainfall is equal to or somewhat exceeds the amount of potential evapotranspiration. For more information on the definitions and concepts of soil moisture regimes, refer to Soil Survey Staff, USDA-NRCS (2014).

guidance maps, supplemental information, and "user notes" for the appropriate application of the F21 – Red Parent Material hydric soil field indicator provided in this chapter. The data limitations result from the large scale of the mapping effort and inherent variability associated with soils and geologic source materials. As previously noted, RPM guidance maps in this chapter only represent the composite of both soils and geological data where problematic RPM can potentially occur based on CCPI analyses of soil samples and pertinent parent material information provided by project collaborators. The mapping project intentionally did not consider other factors relevant to hydric soils (or wetlands) such as drainage class, climate, slope, etc. Therefore, data limitations are presented in reference only to the soils and geological data used to generate RPM guidance maps. Future work regarding the continued identification of problematic RPM is discussed at the end of this section of the chapter.

General Strategy, Site Selection, and Soil Sampling

Soils information in this chapter represents areas where CCPI analysis and published reports provided adequate information for correlating soils series information with parent material and geological information. Site selection for sampling in this study relied heavily on the initial distribution of project letters sent to collaborators (USDA-NRCS MLRA and USACE District offices, etc.) in the late winter/early spring of 2015, as well as the expertise of field personnel familiar with the RPM phenomenon in their corresponding regions. Generally, greater participation in site selection/sampling, and collaboration in the production of RPM guidance maps, occurred with field personnel from areas defined in the Northeast and Mid-Atlantic and Great Lakes RPM regions of this study.

Regarding sampling, a small number of project participants failed to identify the sampled soil series, requiring that soil series for samples be determined using Web Soil Survey and the soil profile description provided. At times, soils collected from KSSL archives were sampled as many as fifty years ago, and the associated soils information may not have been updated to contemporary series designations.

Laboratory Analyses

Due to the large number of samples undergoing analysis, limited replication of the CCPI was completed for each individual soil examined. However, an internal standard was used with each CCPI analysis to monitor quality control; and previous research has demonstrated limited variability between replicate CCPI runs (Berkowitz et al., 2018). As previously noted, the mean CCPI value of all samples analyzed for a particular site was ultimately used to group sites into categories of problematic and non-problematic RPM defined in Rabenhorst and Parikh, (2000). Soil series in the "potentially problematic" range ($30 < CCPI < 40$) were also included in RPM guidance maps if the soil series met criteria (provided above) utilized to generate lists of potential RPM soil series in the mapping phases of the project. This was done to avoid exclusion of potential problematic RPM associated with materials that displayed color change resistance.

Identification of Problematic Red Parent Material

As previously noted, a "soil series," generally, represents a group of soils with a certain range or expression of similar characteristics and properties that differentiate bodies of soil from each other in a landscape. Therefore, the possible expression of the RPM phenomenon and/or morphological requirements to meet the F21 – Red Parent Material hydric soil indicator can vary for each soil series identified in this chapter. It is also important to note that a soil series is not always established or created based on similar geological or parent material characteristics, but also on a variety of other soil properties and site characteristics relevant for land use (landscape position, landform, rock fragment content, etc.). These characteristics and properties are defined at the discretion of USDA-NRCS field personnel. Furthermore, the amount and detail of information provided on the characteristics and properties defined for a given soil series also varies. To date, more than 18,000 soil series have been established nationwide, precluding the evaluation of each soil series to identify them as potential problematic RPM.

Generation of F21 – Red Parent Material Guidance Maps

RPM guidance maps provided in this chapter were generated using the U.S. General Soil Map (STATSGO2) Database. As previously noted, the U.S. General Soil Map (STATSGO2) database is used for mapping purposes on regional, multi-state scales (1:250,000). Thus, map units identified as problematic RPM are intended to reflect areas where problematic RPM may be present. Also, areas included in the RPM guidance maps required five percent or more of a map unit component to contain a soil series identified as potential problematic RPM as defined in the U.S. General Soil Map (STATSGO2) Database.

Geological Data

Like soil series data, there is also great variability in the amount and types of characteristics/properties of rocks and rock sequences used to group geological strata into members, formations, groups, etc. As a result, the geological data described herein is limited by the amount of detail provided by project collaborators' data available within Official Soil Descriptions (OSDs), Block Diagrams and other resources. Furthermore, data limitations regarding the use of state bedrock datasets used to map problematic RPM are generally outlined in USGS Open-File Report(s), available on the USGS website (*https://mrdata.usgs.gov/geology/state/*). Briefly, the chief limitations of these geological data include:

1) differences in scale in which some states have mapped geological units with significantly more detail than others;
2) differences in combined map units in which states have grouped and/or separated out geological strata as members, formations, groups, etc. in digital map units in a variety of ways;
3) differences in exposure in which states differ in the amount of bedrock that is exposed at the surface; and
4) differences in mapping philosophy in which states place different emphasis on particular characteristics of the geology in the state (e.g. structural geology, paleontology, geomorphology, etc.).[101]

As a result of these limitations, the contacts at state boundaries where geological units overlap may lack continuity.[102] Geological map units were identified

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[101] These data limitations also hold true for the variety of other geological datasets (glacial, surficial, etc.) collected and used to map problematic RPM for this project. See Appendix C and D for a list of all references and geological datasets used to map problematic RPM as shown in this chapter.

as problematic RPM at state contacts/across state boundaries where CCPI data was available, if comment was provided to include/exclude geological map units by project collaborators, and by referencing scientific literature.[103] It should also be noted that glacial and surficial geological datasets often fail to link glacial and surficial deposits to their source rocks, posing challenges to the identification and mapping of some problematic RPM. Overall, a general awareness on the locality of red-colored strata in the formations identified as problematic RPM is recommended for making F21 hydric soil determinations in conjunction with the information and maps provided in this chapter.

Opportunities for Additional Research

Future work should focus on refining national RPM guidance maps based upon application of the hydric soil indicator F21 – Red Parent Material by practitioners in the field. Increased consultation and collaboration with wetland, soil, and geological scientists should also be pursued in areas where problematic RPM has been identified to further correlate soils and geological datasets with problematic RPM in this project at/across state boundaries. This is especially true for areas in the South-Central and Desert Southwest and Western Mountains RPM regions where sample submission was limited compared to other regions.

Future work could also incorporate datasets specifically relevant to wetlands to align the maps herein with the occurrence of hydric soils developed in problematic

[102] Also described in the USGS Open File Report(s), no effort was made to resolve boundary mismatches between states in the original state bedrock datasets used to map RPM in this chapter. Error correction and updating of state maps varies considerably and is described in the metadata accompanying each state bedrock dataset created from the NSA projects. See Appendix C for more information.

[103] Additional references used in the literature to confirm geological units as problematic RPM at/across state boundaries are also provided in Appendix D of this document.

RPM. For example, evaluation of the problematic RPM maps using hydric soils lists, U.S. Fish and Wildlife Service's National Wetlands Inventory data, and other tools may prove useful at local and regional scales. Also, utilization of higher resolution soils and geological datasets (where available) could further refine results.

As previously noted, additional data collection and CCPI analyses would help to further constrain the extent of problematic RPM in many of the areas. Specifically, limited data was submitted within the Desert Southwest and Western Mountains RPM region, as well as the Michigan Basin areas in the Great Lakes RPM region. Lastly, while this problematic RPM mapping project has determined various areas and kinds of deposits where problematic RPM are possible to occur throughout the country, an ongoing study of the underlying causes leading to PRPM soils (Mack et al., in preparation) may prove beneficial in further understanding and predicting where problematic RPM occurs.

Conclusions

Hydric soil field indicator, F21 - Red Parent Material, has been approved for nationwide testing in areas containing problematic red soils that are resistant to redox-induced color changes. The CCPI has been established as a repeatable methodology to identify problematic RPM, promoting the appropriate use of F21 across the nation. Prior to the development of this chapter, the spatial occurrence and extent of PRPM soils and their parent materials was unknown. As a result, guidance regarding the appropriate use of the F21 indicator was lacking. For these reasons, a nationwide effort was coordinated between the UMD, USDA-NRCS, USACE, and KSSL to collect and identify areas containing PRPM soils and their derivative parent materials.

A set of guidance maps was generated to support the appropriate application of the F21 indicator.

Based on ~1200 individual soil samples analyzed for CCPI from ~450 sites from around the country, four major regions (Northeast and Mid-Atlantic, Great Lakes, South-Central, and Desert Southwest and Western Mountains) containing problematic RPM were identified for the application of the F21 indicator. In each of these RPM regions, diverse groups of soils and parent materials exhibited problematic RPM characteristics. Despite the observed variability, all problematic RPM areas occurred in association with sedimentary, hematite-rich terrestrial “red bed” formations, and the recently deposited (alluvial, colluvial, and glacial) materials derived from them. Most of the red bed deposits developed under similar depositional environments throughout Earth’s geologic history when areas on the Earth experienced mass deposition of terrestrial sediments carried from upland sources to near-shore, marginal-marine environments.

The RPM guidance maps, supplemental information, and “user notes” within this chapter provide guidance and aid practitioners in overcoming obstacles in accurately identifying hydric soils derived from problematic RPM. Maps and tables link soil series, geological formations, and parent materials containing problematic RPM with USACE Regional Supplement Regions, LRRs, and MLRAs; allowing users to rapidly identify potential PRPM soils through a variety of pathways. For example, problematic RPM can be identified based upon information regarding either soil series names or geologic formation names within a given portion of the nation (e.g., Atlantic Gulf Coastal Plain Region; LRR T). Supplemental information and “user notes” further aid practitioners in recognizing the characteristics of PRPM soils and landforms within each region.

Notably, the guidance maps developed encompass all areas exhibiting problematic RPM, including both wetland and upland area. As a result, identification of hydric soils requires both 1) the presence of problematic RPM as determined by the maps herein, associated soil series or formations, or CCPI analysis, and 2) the requirements of the F21 – Red Parent Material hydric soil field indicator. Further, for an area to be identified as wetland, areas impacted by problematic RPM must also display indicators wetland hydrology and hydrophytic vegetation as required by the procedures outlined in the USACE Wetland Delineation Manual and associated Regional Supplements.

Chapter 4: Hematite and the Fundamental Cause of Red Parent Material Hydric Soils

Introduction

It has long been recognized that some red soils, derived from certain red parent materials (RPM), have weak expression of gray, low-chroma color patterns (i.e. iron depletions) normally used to identify hydric soils in the field (referred to as PRPM soils herein). The earliest cases of this phenomenon are documented in laboratory studies where (under reducing conditions) red soil materials derived from certain deposits developed low-chroma, gray colors more slowly, suggesting that the iron oxide pigments responsible for soil color actually resist redox-induced color changes (Niroomand and Tedrow, 1990; Sprecher and Mokma, 1989; Mokma and Sprecher, 1994; Elless et al., 1996). Additional field research attributed this resistance to color change in these PRPM soils to the presence hematite in the soils, without specifying a particular mechanism (Mokma and Sprecher, 1994).

Later, mineralogical studies in PRPM soils of the Culpeper basin of MD indicated that hematite was the only pigmenting iron oxide in the subset of soils examined (Elless and Rabenhorst, 1994). The mechanism for this resistance to form redox-induced colors was suggested to be due to Al for Fe substitution in the hematite structure (Elless and Rabenhorst, 1994) as previous studies observed that increased Al substitution caused goethite and hematite to be less easily reduced in field soils (Oxisols) and synthesized minerals in laboratory settings (Fey, 1983; Macedo and Bryant, 1987; 1989; Bryant and Macedo, 1990; Cornell and Schwertmann, 2003). Despite these studies, no conclusive evidence has confirmed the presence of Al substitution in PRPM soils, and comparisons between the (mineralogical) characteristics of PRPM and non-problematic soils are lacking.

Previous observations of PRPM soils led to the development of a field indicator, TF2 – Red Parent Material, approved for testing in wet soils derived from RPM throughout the country. The indicator required that soils be dark red (hues of 7.5YR or redder, value and chroma 4 or less) and also contain at least 2% redoximorphic features (as concentrations and/or depletions in combination) to indicate the presence of hydric conditions (USDA-NRCS, 1998). User notes for the indicator also provided examples of appropriate types of geologic materials from which these problem soils might be derived. These were mostly Mesozoic and Paleozoic-aged, red sedimentary rocks and materials derived from them, as well as some basic, igneous and metamorphic crystalline rocks (associated with the Congaree River and its floodplains) (USDA-NRCS, 1998).

In an attempt to quantify how easily red soils develop low-chroma, gray colors under reducing conditions, the Color Change Propensity Index (CCPI) was developed (Rabenhorst and Parikh, 2000). The CCPI procedure requires the incubation of soils with a highly reducing chemical agent in laboratory settings (both at room and elevated temperatures) and then measuring changes in their soil color (Munsell hue, value, and chroma) over time using a digital colorimeter. From the changes in soil color (specifically a combination of changes in hue and chroma), a numerical relationship was developed to distinguish which red soils are inherently resistant to color change (i.e. problematic) from those that are not, and soils must qualify as “problematic” with CCPI values less than 30 (Rabenhorst and Parikh, 2000). The CCPI was later incorporated into the definition of “red parent material” in a newly revised field indicator, F21 – Red Parent Material, replacing the original TF2 indicator in version 8.0 of the *Field Indicators of Hydric Soils of the United States* (USDA-NRCS, 2017a). The revised F21 indicator requires that soils be dark red in color (hues of 7.5YR or redder, value and chroma less than 4). But in contrast to TF2, the F21 indicator requires 10% redoximorphic features (as concentrations and/or depletions in combination), rather than 2% to indicate the presence of hydric soil conditions (USDA-NRCS, 2017a).

With the development of the revised F21 field indicator, a collaborative, hydric soil mapping project was undertaken by the Pedology Laboratory at the University of Maryland, the United States Army Corps of Engineers (USACE), the USDA-Natural Resources Conservation Service (USDA-NRCS), and the Kellogg Soil Survey Laboratory (KSSL), to identify the potential occurrence of PRPM soils for F21 wetland determinations throughout the country using CCPI technology (Chapter 3). Results from the mapping project demonstrated that the potential occurrence of PRPM soils is widespread (occurring in 27 U.S. states across four major regions that span from MA to WY), and confirmed that the problematic soils are formed from old (mostly Paleozoic and Mesozoic) sedimentary rocks known as “terrestrial red beds,” and the recently transported materials (glacial, alluvial, colluvial) derived from them (Chapter 3). In each of these deposits, hematite is known to be the predominant or only iron oxide pigment present in the deposits (Chapter 3, Van Houten, 1973; Walker, 1976; Torrent and Schwertmann, 1987).

Hematite, however, is also known to be present in many red soils that are not problematic (Chapter 3).

Interestingly, another defining characteristic of PRPM soils is their dark, red-purplish[104] color (Chapter 3), and the influence of iron mineralogy on the colors of many RPM deposits has been investigated. For example, in the (Triassic) Moenkopi formation, a terrestrial red bed known to produce PRPM soils in the Colorado Plateau region of the western U.S., the crystal size of the hematite was found to range in size from ultrafine (crystals not evident when magnified 50,000 times) to coarse specular hematite (2 - 40 μm), producing differences in the colors of deposits' red pigments (Walker et al., 1981). While not identified as PRPM in the U.S., several lithologically-related (Triassic) red beds in Germany were found to have larger crystals of hematite (2 - 5 μm) in purplish-colored horizons of the deposits, suggesting that increasing grain size of the mineral turns the color of the deposits from red to purple (Heim, 1970; Mader, 1982). Likewise, Schwertmann (1993) demonstrated that the size of iron oxide crystallites has an effect on soil color. Particular to hematite, soils with larger hematite crystals have been shown to be darker, and more purple color, while soils with smaller hematite crystals appear brighter red (Schwertmann, 1993). While the crystal size of hematite has been documented to explain the dark reddish-purple colors of many terrestrial red beds known to be parent materials of PRPM soils, as well as play a role in impacting soil

[104] References to a "purplish" or "purple" color observed in PRPM soils is not meant to imply that the soils are purple (RP or P) in hue by the Munsell color system. The term "purple" or "purplish" is used in a more general sense to describe the dark, deep shades of red color observed (where values and chromas were all less than or equal to 4). Hues of all PRPM soils in this study ranged between 7.5YR and 2.5YR using the Munsell color system (Chapter 3; see Appendix B for reference).

color, hematite crystal size has not been explored as a possible cause for PRPM soils to resist to color change.

Furthermore, another possible explanation for why PRPM soils resist color change is the phenomenon of physical occlusion where iron oxides may be physically isolated from microbially-induced reduction. In soils, this phenomenon of physical occlusion has been documented as the cause the formation of a variety of other soil morphological features. For example, in surface horizons of organic-rich soils, the physical separation and isolation of soil organic carbon sources from microbial organisms in and across soil aggregates has been attributed to the aggregation of soil peds, maintenance of soil structure, long-term carbon storage, and the subsequent darkening the surface horizons (Six et al., 2000; Virto et al., 2008; Schrumpf et al., 2013). Specifically in saturated soils, the physical separation of oxygen and moisture from the interior and/or exterior of soil peds has also been known to influence the patterns and distributions of redoximorphic features observed in the profiles of periodically saturated and/or hydric soils (Fanning and Fanning, 1989; Vepraskas and Sprecher, 1997). These patterns are often denoted by field scientists by describing the location redoximorphic features are observed in a soil profile, such as on ped surfaces, in pore linings, and/or along root channels (USDA-NRCS, 2017a).

In PRPM soils, however, the iron oxides (that produce the overall red pigment) may be physically isolated from microbially-induced reduction by being cemented within small (silt and fine sand sized) lithic fragments. Typically, in soils, iron oxides exists as a thin veneer or coating on the exteriors of soil mineral grains of various (sand, silt and clay) sizes (Schwertmann, 1993; Bigham et al., 2002; Van

Houten, 1973). In PRPM soils, the coarser (sand and silt) fractions of soils derived from sedimentary red beds contain a variety of grains. While some of these are individual mineral grains of primary minerals (quartz, feldspars, micas, etc.), some of these individual sand and silt grains are lithified fragments of the parent sedimentary rocks. As such, they are comprised of smaller fine silt and clay sized particles (also coated with Fe oxide pigments) that are cemented and occluded within the interior of the grains. The red colors of these "interior" iron oxides are visible "through" the cemented primary mineral grains surrounding and protecting them on the exterior. When reducing conditions develop within these soils, iron oxides on the exterior of the grains are solubilized, but the iron oxides within the interior may be protected and therefore preserve their overall red pigment. This phenomenon of physical occlusion has yet to be explored as a possible cause for the occurrence of PRPM soils, in addition to the possible mineralogical causes addressed prior.

Although the phenomenon of problematic RPM is extensive and well documented (Chapter 3), the actual mechanism causing their resistance to color change, or their "problematic" nature that inhibits the development of gray, low-chroma colored redox depletions, is uncertain. Therefore, the overall objective of this chapter is to determine the mechanism responsible for the "problematic" nature regarding the hydromorphology of these red soils. Three hypotheses were explored: 1) the physical occlusion of iron oxides within lithified, sedimentary rock fragments in sand and silt fractions; 2) Al for Fe substitution within the crystal structure of hematite; and 3) the crystallite size of hematite, in PRPM soils.

Materials and Methods

General Strategy

Each of the three hypotheses were addressed independently by comparing results for problematic and non-problematic soils containing hematite. The physical occlusion hypothesis was evaluated by performing the CCPI procedure on a wide range of particle size fractions (i.e. sands, silts, and clays) of problematic and non-problematic samples with the expectation that occlusion would occur in larger particle-size fractions containing small rock fragments (aggregates), such as silts and sands, whereas clays would be non-aggregated, individual mineral grains coated with iron oxides. Therefore, if occlusion is the cause for color change resistance, occluded fractions (i.e. silts and sands) would demonstrate a low CCPI, whereas the clay fraction would not. The Al substitution hypothesis was evaluated by determining the degree of Al substitution in the hematite of problematic RPM soils using shifts in XRD peaks characteristic for the mineral. If Al substitution is the cause, problematic soils should contain substantial Al substitution, and also at greater levels than non-problematic soils. Finally, the crystal size hypothesis was evaluated by calculating the mean crystallite size of hematite in problematic and non-problematic soil samples by examining XRD peak broadening and applying the Scherrer equation. If crystal size is the cause, larger crystals of hematite should be observed in problematic soil samples than in the hematite of non-problematic soil samples.

Sample Selection and Acquisition

Twelve problematic soil samples were collected from sites across the four major regions where problematic RPM soils have been identified (Chapter 3). Four non-problematic soil samples were also collected for comparison. Selection of the sampling sites for problematic soils was based upon prior CCPI analyses and the intention to include soils representative of the four main regions where RPM was identified (Chapter 3). Sampling sites for non-problematic soils were selected based on prior knowledge that the soils were not resistant to color change, but were: red in color, derived from parent materials also red in color, and believed to contain hematite (Figure 4.1).

Figure 4.1. *Location of sampling sites for problematic and non-problematic soils collected from the four major RPM regions (GR = Great Lakes, MA= Northeast & Mid-Atlantic, SC = South-Central, DS&RM = Desert Southwest and Western Mountains (Chapter 3).*

All soils sampled were collected from subsurface horizons (B or C horizons). Site characteristics for each soil is described in Table 4.1.

Table 4.1. Site characteristics of problematic (P1-12) and non-problematic (NP1-4) soils from the four major RPM regions.

Sample ID	Horizon	Depth (cm)	RPM Region	State	Soil Series	Parent Material/Geology
P1	C	8-27	DS&RM	UT	Moenkopie	Sandstone residuum from the Permian Carmel Formation
P2	Bt	58-86	GL	MN	Badriver	Wisconsinan-aged, glacio-lacustrine deposits derived from red, Precambrian-aged sedimentary rocks of the Superior Basin
P3	Bt3	61-97	GL	WI	Hortonville	Wisconsinan-aged, glacio-lacustrine and till deposits of the Kewaunee Formation
P4	Bt1	25-51	MA	WV	Cateache	Siltstone and mudstone residuum from the Mississippian Mauch Chunk Formation
P5	Bt1	16-43	MA	NY	Ovid	Glacial till derived from red members of the Silurian Salina Group
P6	Bt2	43-69	MA	WV	Peabody	Residuum from red members of the Carboniferous Conemaugh Group
P7	Bt1	20-35	MA	MD	Reaville	Red shale residuum from the Triassic Gettysburg Formation (Newark Supergroup)
P8	Btx	69-102	MA	NJ	Wethersfield	Glacial till derived from the Triassic/Jurassic-aged Feltville and Passaic Formations (Newark Supergroup)
P9	Bw2	53-70	MA	CT	Wilbraham	Glacial till derived from the Triassic/Jurassic-aged Portland Formation and New Haven Arkose (Newark Supergroup)
P10	Bss2	34-55	SC	TX	Brazoria	Clayey, Brazos River alluvium sourced from Permian Red Beds in west-central TX
P11	Bw2	55-74	SC	LA	Moreland	Clayey, Red River alluvium sourced from Permian Red Beds in central OK and north-central TX
P12	Bk1	18-33	SC	TX	Vernon	Red shale residuum of the Permian Clearfork Group
NP1	Bt1	28-70	-	MD	Christiana	Unconsolidated, fluviomarine, Coastal Plain deposits of the Potomac Group
NP2	Bt1	17-29	-	VA	Davidson	Residuum from dark-colored metavolcanic and metasedimentary, Cambrian-aged rocks high in ferro-magnesian minerals
NP3	Bt2	35-68	-	AL	Gwinnett	Residuum from Precambrian to Paleozoic-aged schists, gneisses, and other basic crystalline rocks of the Dadeville Complex, Waverly Gneiss, etc.
NP4	Bt1	38-50	-	MD	Hagerstown	Limestone residuum of the Cambrian/Ordovician-aged Conococheague Formation

**DS&RM= Desert Southwest and Western Mountains, GL= Great Lakes, MA = Northeast and Mid-Atlantic, and SC = South-Central (Chapter 3).*

<u>Laboratory Analyses</u>

Bulk soils were air-dried, sieved, and evaluated for their water content. Subsamples were then prepared for particle size analysis, particle size fractionation, and CCPI analysis to address the hypothesis of physical occlusion. Iron extractions were also performed on bulk soil materials, as well as on clay fractions collected via particle size and fractionation methods. Clay and iron mineralogy were qualitatively characterized for each soil using X-Ray Diffraction (XRD), in addition to determining the degree of Al substitution and the mean crystallite size of hematite for each soil sample.

Particle Size Analyses and Fractionation

Particle size analysis was performed in duplicate following the pipette method (Gee and Orr, 2002). Based on results from particle size analyses, between 50 and 300 g of soil was fractionated into 9 particle size fractions: very coarse sands (2-1 mm); coarse sands (1–0.5 mm); medium sands (0.5-0.25 mm); fine sands (0.25-0.10 mm); very fine sands (0.10-0.05 mm); coarse silts (50-20 µm); medium silts (20-5 µm); fine silts (5-2 µm); and clays (< 2 µm). To do this, soils were weighed into 250 mL nalgene bottles (50 g per bottle) to each of which 20 mL of sodium hexametaphosphate was added. These were shaken on a rapidly oscillating shaker (at approximately 200 OPM) for 30 minutes. Dispersed suspensions were then sieved through a 325 mesh (45 µm) sieve. The portion passing through the sieve (silts and clays) was further separated into coarse (50-20 µm), medium (20-5 µm), fine silt (5-2 µm), and clay (< 2 µm) fractions by sedimentation techniques. The sands (that were retained on the sieve) were dried and then further separated into very coarse (2-1 mm), coarse (1–0.5 mm), medium (0.5-0.25 mm), fine (0.25-0.10 mm), and very fine (0.10-0.05 mm) sand fractions by sieving. Clays were concentrated by flocculating with $MgCl_2$. Excess salts were removed by centrifuge washing. When clays began to disperse during centrifuge washing, clays were then dried by placing on a freeze dryer.

Color Change Propensity Index (CCPI)

CCPI values were determined on bulk soils and on the individual particle size fractions using the method described by Rabenhorst and Parikh (2000). To ensure adequate sample size for analyses (5 g needed for CCPI), the very coarse and coarse sand fractions, as well as the very fine and fine sand fractions, were recombined prior to analysis. Soil colors (for calculating CCPI) were measured with a Konica-Minolta digital colorimeter, with [Munsell] hue, value, and chroma measured to the nearest 0.1 unit. As described in Rabenhorst and Parikh (2000), color was measured under three different conditions: 1) initially after saturation with citrate buffer (CB) solution (pH 7, no sodium dithionite added) at room temperature (25°C); 2) after treatment with dithionite-citrate-buffer (DCB) at room temperature (25°C) for 1 hour; and 3) after treatment with DCB at 80°C for 4 hours. Bulk soils and individual fractions were then grouped into three classes based on their CCPI values: problematic if the CCPI < 30, non-problematic if the CCPI > 40, and "potentially problematic" if the CCPI was between 30 and 40 (Rabenhorst and Parikh, 2000).

Iron Extractions

Total DCB extractable iron was determined on the bulk soils and the fractionated clays following a modification of the method by Kittrick and Hope (1963). Duplicate 1.0 g (bulk soil) and 0.33 g (clay) subsamples from each soil were treated with 0.4 g sodium dithionite and 14 mL of a CB buffer solution (pH 7) in a 20 mL centrifuge tube. These were then placed in a water bath at 80°C for 4 hours (each sample was rigorously stirred in the tube approximately every 45 minutes over the 4-hour period). Tubes were centrifuged, and the supernatant was transferred to 100 mL volumetric flasks. This extraction process was then repeated a second time, and the extractant was brought to 100 mL in the volumetric flasks with deionized water. Concentrations of iron were then determined on duplicate diluted fractions of the extractants using Atomic Absorption spectrophotometry.

Clay Mineralogy

Mineralogy of the clay fractions was characterized using XRD. Duplicate subsamples (0.2 g) of the clays were saturated with either 1.0 M KCl or 0.5 M $MgCl_2$ by repeated centrifuge washing before being preferentially oriented on a glass slide using the method described by Drever (1973). The $MgCl_2$ saturated samples had 10% ethylene glycol added and were also placed in a desiccator overnight with 10% ethylene glycol to further facilitate the expansion of the expansible minerals. The XRD patterns were collected using a Panalytical PW1830 X-ray diffractometer equipped with a Cu tube and a curved crystal graphite monochrometer and a sealed Xe proportional detector. Samples were continuously scanned from 4 to 60°2θ at a rate of 1.2°2θ min^{-1}. Separate scans were run on the KCl saturated samples at room temperature (25°C), and after heating to 300°C and 500°C for 2 hours in a muffle furnace (Harris and White, 2008).

Iron Mineralogy

Iron mineralogy of each soil was also characterized using XRD. Because iron oxides typically constitute a small percentage of soils, and are mostly associated with the clay fraction, an attempt to concentrate the iron oxide minerals in the clay fractions for each soil was also performed using a 5 M NaOH digestion as described by Kämpf and Schwertmann (1982). Following digestion, centrifuge washing, and dialysis, the digested clay subsamples were then freeze dried and analyzed by XRD as random powder mounts. Continuous XRD scans were run as before, from 4 to 60°2θ at a rate of 1.2°2θ min^{-1}, and also at a slower rate of 0.12°2θ min^{-1} in the vicinity of the iron oxide peaks from 32 to 38°2θ.

Calculations of Al Substitution

In order to quantify Al for Fe substitution in hematite, peak shifts at the (300) [hkl] peak for hematite were determined using XRD scans on random power mounts of the 5 M NaOH digested clay fractions spiked with LaB_6. The powder mounts were step-scanned at intervals of 0.01°2θ from 63 to 64.5°2θ and counted for 5 seconds per step (approx. 0.075°2θ min^{-1}). The (220) [hkl] peak for LaB_6 (d = 63.22 Å for CuKα1) were used to align the XRD patterns in order to carefully document the shift in the (300) [hkl] hematite peak. The displacement of the 300 [hkl] peak was used to calculate the a_o-dimension [e.g. size along the (100) axis] of the hematite unit cell in each subsample (Wells et al., 2001). This a_o-dimension of the hematite was then used to estimate the % mol Al substitution in the mineral for each soil using the relationship published by Schwertmann et al. (1979).

Crystallite Size Calculations and the Scherrer Equation

Mean crystallite size of hematite in soils was determined using the slower XRD scans (32 to 38°2θ at rate of 0.12°2θ min^{-1}) on random powder mounts of the 5 M NaOH digested clays. Crystal sizes were estimated using the Scherrer equation and measurements of the Full Width at Half Maximum (FWHM) of the (110) [hkl] peak (d = 2.51 Å for CuKα1) for hematite. Corrections for instrument broadening were made using scans of LaB_6 (Klug and Alexander, 1974).

Results and Discussion

Soil Properties

Soil properties of the 16 samples are presented in Table 4.2. Particles size classes were mostly loamy with a few clayey textures. None were particularly sandy. Both problematic and non-problematic soil samples were all red in color (Hue 2.6 - 7.1YR). Regarding extractable Fe content, most (14/16) had bulk DCB-Fe values below 3.5% and two of the non-problematic samples (NP2, NP3) were substantially higher (8-10%). As expected, Fe content of the clay fraction was higher for all samples with the problematic samples ranging from 1.3 to 4.8% Fe and the non-problematic samples ranging from 7.5 to 13.1% Fe. The higher Fe content in the non-problematic samples suggests that the "problematic" nature of PRPM soils is not a matter of high % Fe.

Table 4.2. Soil properties of problematic and non-problematic soil samples.							
Sample ID	**Soil Color** Hue (Value/Chroma)	**% S**	**% Si**	**% C**	**Particle Size Class**	**% Fe (Bulk)**	**% Fe (Clay)**
P1	4.1YR (4.0/4.1)	77.6	12.7	9.8	SL	0.3 ± 0.02	1.3 ± 0.07
P2	3.6YR (3.6/3.5)	24.4	25.3	50.4	C	2.0 ± 0.05	2.8 ± 0.11
P3	6.1YR (4.4/3.7)	43.6	29.2	27.2	CL	1.4 ± 0.06	3.5 ± 0.11
P4	6.3YR (4.1/3.1)	25.5	41.5	33.0	CL	2.5 ± 0.06	4.8 ±0.06
P5	3.5YR (3.9/2.5)	38.3	28.0	33.7	CL	1.7 ± 0.02	3.7 ± 0.28
P6	4.5YR (3.9/3.2)	31.5	41.7	26.9	L	2.2 ± 0.03	4.7 ± 0.20
P7	2.9YR (3.5/3.8)	30.9	56.0	13.1	SiL	1.9 ± 0.10	3.6 ± 0.17
P8	4.4YR (3.4/2.8)	64.0	28.2	7.8	SL	1.3 ± 0.04	5.5 ± 0.18
P9	6.0YR (3.9/3.6)	53.8	39.4	6.8	SL	1.0 ± 0.04	3.8 ± 0.07
P10	5.8YR (3.7/2.7)	2.7	25.5	71.8	C	1.4 ± 0.05	1.6 ± 0.07
P11	4.8YR (3.6/3.6)	1.9	56.7	41.5	SiC	1.2 ± 0.03	2.0 ± 0.10
P12	2.8YR (3.7/3.8)	13.5	41.2	45.3	SiC	1.7 ± 0.05	2.8 ± 0.06
NP1	4.3YR (4.6/5.0)	29.1	46.8	24.2	L	2.5 ± 0.06	7.8 ± 0.24
NP2	2.6YR (3.7/4.9)	10.4	17.5	72.0	C	9.8 ± 0.38	13.1 ± 0.25
NP3	3.9YR (4.3/5.6)	27.8	29.2	42.9	C	8.7 ± 0.20	10.6 ± 0.20
NP4	7.1YR (4.6/4.9)	15.1	49.8	36.1	SiCL	3.2 ± 0.05	7.5 ± 0.20

A summary of the clay and iron mineralogy determined on the fractionated clay subsamples of each soil is shown in Table 4.3. For clay mineralogy, results varied substantially across the different sites. Overall, the bulk of the samples are dominated by 2:1 layer silicates, with some dominated more by kaolinite. For all bulk soils, the Fe oxides (hematite and goethite) represented a fairly small component (< 10%) of the samples. All problematic soils showed evidence of hematite as the only pigmenting oxide, while all of the non-problematic samples contained both goethite and hematite which the exception of one non-problematic sample (NP4) that did not contain sufficient hematite to detect the (110) [hkl] peak. All X-Ray diffratograms used to assess the clay and iron mineralogy of these soils are presented in Appendix E of this document.

Table 4.3. Qualitative assessment of clay and iron mineralogy of problematic and non-problematic soil samples.

Sample ID	Mineral							
	Smectite	**Vermiculite**	**HIV (Chlorite)**	**Mica**	**Kaolinite**	**Quartz**	**Hematite**	**Goethite**
P1				XXXX	X	X	Tr	
P2	X	X	XX	XX	XX	XX	X	
P3		XX	X	XX	XX	XX	X	
P4		XX	Tr	XX	XXX	X	X	
P5			XX	XXX	XX	X	X	
P6		XX	X	XX	XXX	X	X	
P7		XX	XX	XX	XX	XX	X	
P8		X	X	XXX	XX	XX	X	
P9		XX	XX	XX	XX	XX	X	
P10	XX		XX	XX	XX	XX	Tr	
P11	XX		XX	XX	XX	XX	Tr	
P12	XX		XX	XX	XX	XX	Tr	
NP1				XXX	XXX	X	X	X
NP2		XX	XX		XXX	X	X	X
NP3					XXXX	XX	X	X
NP4		X	Tr	XX	XXX	XX		X

**HIV = Hydroxylated-interlayered vermiculite. XXXX = > 70%, dominant. XXX = 70-30%, high. XX = 30-10%, moderate. X = <10%, low. Tr = Trace. X-Ray diffractograms used to characterize the clay and iron mineralogy for each soil are provided in Appendix E of this document.*

Physical Occlusion and the CCPI

PRPM soils all contained red-colored, lithic fragments of the red bed, sedimentary rocks from which they are derived in the sand- and silt-sized fractions (Figure 4.2). These lithic fragments may contain physically occluded iron oxide that cannot be accessed and reduced by soil microorganisms. If occlusion of iron oxides within these lithic fragments is the overall cause of these problematic soils resisting color change, the occluded fractions would be expected to demonstrate a low CCPI, whereas the clay fractions (which exist as individual particles coated with thin layers of Fe oxides in suspension) would not have a low CCPI.

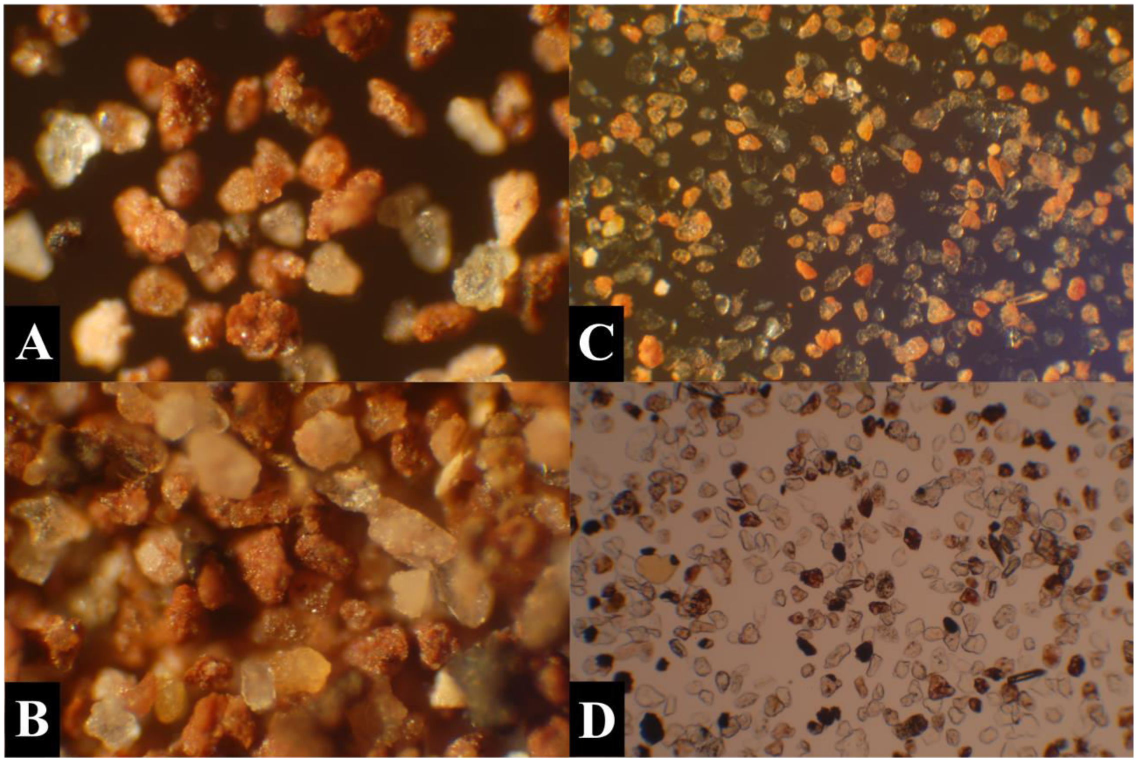

Figure 4.2. *Micrographs of very fine sand (A & B) and coarse silt (C & D) fractions of the Bt1 horizon from the Reaville soil (Sample ID = P7). Note that mineral grains are mostly quartz and red shale fragments. Red shale fragments are small aggregates of lithified sedimentary rock in which iron oxides can be occluded. A, B, and C were taken under incident light (IL), while D was taken under transmitted light (TSML). C and D are in the same field of view, under different light conditions. The frame length for A and B is 800 µm and the frame length for C and D is 300 µm.*

Soil colors and CCPI results from the bulk soil and individual particle size fractions separated for each soil are shown in Table 4.4. and Table 4.5, respectively. Note that the majority of the problematic soil fractions were red in color (7.5YR or redder, value and chroma of 4 or less), while the non-problematic fractions were not as red or were higher in value and chroma. Also note that all of the bulk soils, as well as the fractions for the problematic soil samples, had low CCPI values. For bulk soils and fractions of the problematic samples that were not < 30, most ranged between 31 and 35, which is close to 30 as the threshold CCPI value required for identification of problematic RPM in the F21 field indicator.[105] Most of the non-problematic fractions had high CCPI values greater than 30. Most importantly, the clay fractions (which represent individual particles coated with Fe oxides in suspension) for all problematic samples had low CCPI values (< 30), while the clay fractions for all the non-problematic samples had high CCPI values (> 44). These results indicate that the physical occlusion of iron is not the cause of the PRPM phenomenon, and instead suggests a mineralogical explanation.

[105] The single exception to this was the C and VC fraction of sample P3, which had a CCPI of 123. The starting color for this fraction had a hue of 0.0Y (10YR) and many of the other fractions for the sample were yellower than 7.5YR in hue. The clay fraction also had a hue of 5.5YR, which likely controlled the color of the bulk soil, which had a hue of 6.1YR (Table 4.4).

Table 4.4. Soil color [Hue (Value/Chroma)] of bulk soil and particle size fractions of problematic and non-problematic soil samples.

Sample ID	Bulk Sample	VC + C Sands	Medium Sands	VF + F Sands	Coarse Silts	Medium Silts	Fine Silts	Clays
P1	4.1YR (4.0/4.1)	5.9YR (4.3/4.0)	5.0YR (4.5/4.5)	4.6YR (4.4/4.5)	4.8YR (4.6/3.6)	5.0YR (5.3/3.6)	4.5YR (4.8/3.7)	3.7YR (4.8/4.0)
P2	3.6YR (3.6/3.5)	7.9YR (2.9/1.8)	7.7YR (3.0/1.8)	6.9YR (3.3/3.2)	7.1YR (3.4/2.3)	7.0YR (3.8/2.2)	6.0YR (4.3/2.9)	3.8YR (4.1/3.7)
P3	6.1YR (4.4/3.7)	0.0Y (3.6/2.5)	8.8YR (3.9/2.4)	8.4YR (4.0/2.8)	8.9YR (4.3/2.6)	8.7YR (4.3/3.0)	8.5YR (4.5/3.5)	5.5YR (3.9/3.7)
P4	6.3YR (4.1/3.1)	0.8Y (2.8/2.6)	0.4Y (3.1/2.7)	0.5Y (3.7/2.9)	0.2Y (4.2/2.7)	8.9YR (4.3/2.4)	7.4YR (4.4/2.9)	5.6YR (4.4/3.7)
P5	3.5YR (3.9/2.5)	NF	NF	8.9YR (4.4/2.6)	9.2YR (4.0/2.3)	6.8YR (4.0/4.2)	5.7YR (4.2/2.6)	3.6YR (4.5/3.4)
P6	4.5YR (3.9/3.2)	0.9Y (2.9/2.6)	3.5Y (3.1/2.5)	9.6YR (3.6/3.0)	9.5YR (4.3/2.8)	8.1YR (4.7/3.2)	7.3YR 4.7/3.6	4.9YR 4.4/4.3
P7	2.9YR (3.5/3.8)	5.0YR (2.3/3.1)	4.7YR (2.4/3.0)	4.8YR (2.7/2.8)	4.7YR (3.4/3.5)	4.2YR (3.6/3.3)	4.3YR (3.8/3.3)	5.0YR (3.5/3.0)
P8	4.4YR (3.4/2.8)	5.6YR (2.9/2.1)	4.9YR (3.0/2.8)	4.5YR (3.1/3.0)	4.7YR (3.3/3.2)	4.4YR (3.6/2.9)	4.4YR (3.8/3.0)	4.4YR (3.8/3.3)
P9	6.0YR (3.9/3.6)	5.9YR (3.1/2.7)	6.0YR (3.1/2.9)	5.7YR (3.5/3.4)	5.9YR (3.8/3.5)	6.4YR (4.1/3.3)	6.4YR (4.1/3.4)	5.6YR (4.2/3.6)
P10	5.8YR (3.7/2.7)	6.4YR (2.8/1.5)			NF	NF	8.3YR (4.1/2.3)	5.9YR (3.7/2.8)
P11	4.8YR (3.6/3.6)	6.6YR (2.5/2.0)			6.9YR (3.8/2.8)	7.0YR (4.2/3.0)	6.8YR (4.0/2.8)	4.7YR (3.6/3.3)
P12	2.8YR (3.7/3.8)	4.1YR (2.8/3.0)	4.1YR (3.1/3.0)	4.3YR (3.5/3.3)	4.0YR (4.8/3.6)	3.5YR (3.8/3.5)	2.8YR (3.8/3.7)	2.8YR (3.5/4.2)
NP1	4.3YR (4.6/5.0)	8.7YR (4.2/2.8)	8.7YR (5.0/3.6)	6.5YR (4.5/4.9)	6.9YR (4.4/4.6)	6.0YR (4.8/5.0)	5.7YR (5.2/5.1)	4.3YR (4.8/5.8)
NP2	2.6YR (3.7/4.9)	NF	NF	7.9YR (2.9/2.4)	9.4YR (3.3/2.1)	6.4YR (3.9/3.2)	5.0YR (4.0/4.4)	2.5YR (2.9/5.1)
NP3	3.9YR (4.3/5.6)	8.8YR (5.1/3.9)	8.3YR (4.3/3.1)	7.4YR (5.2/3.5)	6.5YR (4.4/4.4)	5.6YR (4.7/4.6)	5.6YR (4.8/5.6)	3.6YR (4.1/5.6)
NP4	7.1YR (4.6/4.9)	NF	NF	0.3Y (4.3/3.5)	0.8Y (5.1/3.3)	9.8YR (5.1/3.6)	8.8YR (5.0/5.2)	7.0YR (4.7/5.3)

**NF = no fraction collected (too small for CCPI analysis). Gray-shaded values are those where the soil color rounds to 7.5YR or redder, and to value and chroma of 4 or less (colors required for the application of the F21 – Red Parent Material field indicator).*

Table 4.5. Color Change Propensity Index (CCPI) values of bulk soil and particle size fractions of problematic and non-problematic soil samples.

Sample ID	Bulk Sample	VC + C Sands	Medium Sands	VF + F Sands	Coarse Silts	Medium Silts	Fine Silts	Clays
P1	12	6	11	13	17	5	13	15
P2	22	6	4	11	15	15	19	23
P3	22	123	6	18	22	27	25	23
P4	20	24	22	27	22	15	18	23
P5	10	NF	NF	7	9	9	10	15
P6	20	34	27	35	28	32	31	29
P7	9	13	8	6	8	11	10	9
P8	9	5	8	9	13	11	10	14
P9	20	23	7	16	14	19	19	20
P10	22	24			NF	NF	25	29
P11	29	1			29	27	25	24
P12	21	13	18	14	19	20	20	23
NP1	52	5	9	72	73	83	71	44
NP2	48	NF	NF	17	24	40	63	48
NP3	71	456	76	55	63	67	75	64
NP4	112	NF	NF	282	1596	134	117	104

**NF = no fraction collected (too small for CCPI analysis). Gray-shaded values are those where the CCPI value is less than 30 and would qualify as problematic RPM. Also note that non-problematic fractions with CCPI values less than 30 (VC + C sands and medium sand fractions of sample NP1, and VF + F sands and coarse silt fractions of sample NP2) had soil colors that round to yellower hues (0.0Y or 10YR) (Table 4.4).*

Al for Fe Substitution

In work done by Schwertmann (1991), it was demonstrated that the rate of dissolution of synthetic goethites is inversely related to the degree of Al substitution in the mineral (Figure 4.3)

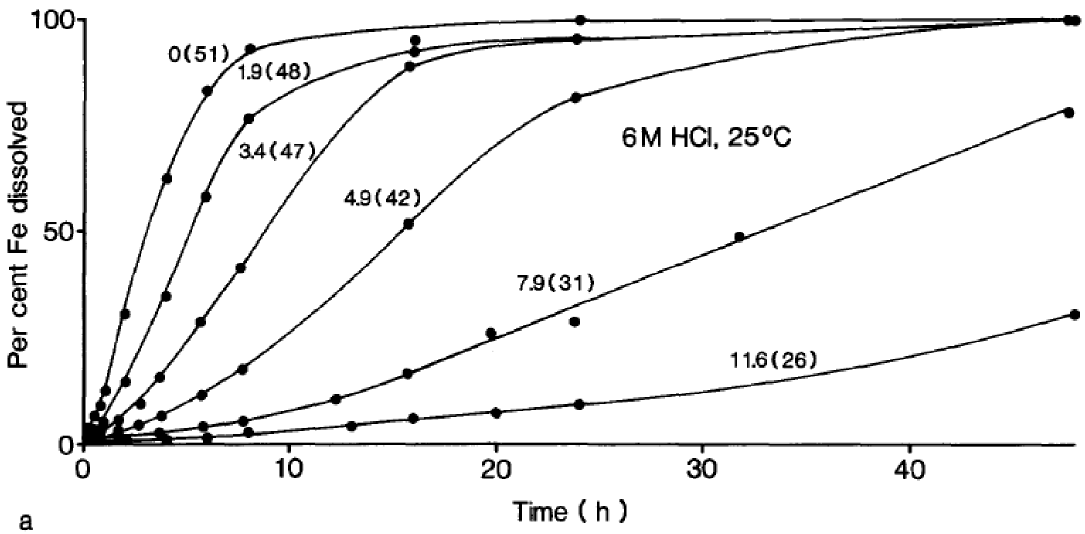

Figure 4.3. *Dissolution-time curves of synthetic Al substituted goethites in 6 M HCl at 25 ℃. The values on the curves indicate Al substitution in mol % and values in ( ) are the surface area of the hematites in m^2g^{-1}. Figure 4a from Schwertmann (1991).*

Macedo and Bryant (1989) invoked this same principle to explain why certain Oxisols were less susceptible to redox-induced dissolution, leading to the formation of yellow soils under wet conditions. Work by Torrent et al. (1987) also demonstrated that the dissolution rates of both synthetic goethite and hematite were lowered by greater Al substitution for Fe in the crystal structure (Figure 4.4). Therefore, if Al substitution in hematite is the cause of PRPM, we would expect the hematite in PRPM soils to contain a high mol % of Al.

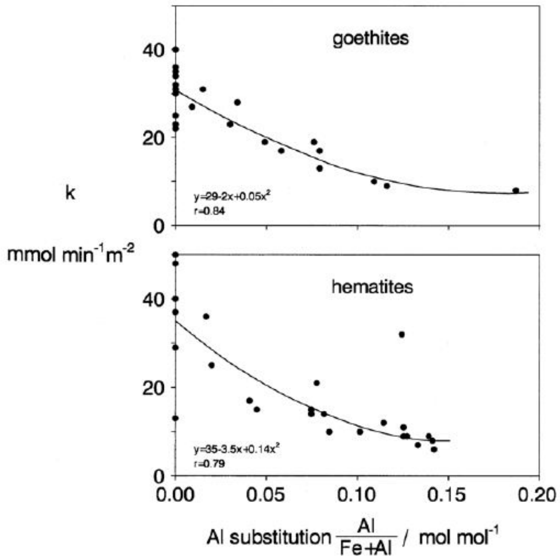

Figure 4.4. *Relationship between the dissolution rate per unit surface area in sodium-dithionite/citrate/bicarbonate at 25 °C and the Al substitution of 28 synthetic goethites (upper) and 24 synthetic hematites (lower). Figure 12.22 from Cornell and Schwertmann (2003), modified from Figures 2 and 4 from Torrent et al. (1987).*

Table 4.6. shows the % mol Al substitution calculated from XRD scans of the 5 M NaOH digested clay fractions for each of the problematic and non-problematic soils. The mean Al substitution for all of the hematite in PRPM soils is about 0.8 (SEM = 0.2) mol %, indicating that the degree of Al substitution in the hematite of the soils is very small. Compared to the total amount of Al that can potentially be substituted for Fe in the hematite crystal (about 16 mol %) (Schwertmann et al., 1979), such small levels of Al substitution suggests that PRPM soils' resistance to color change cannot be a function of high Al substitution in the hematite. This low degree of Al substitution in hematite was also similarly detected in samples of red shales collected from the (Triassic) Culpeper basin in early studies of problematic RPM (mean of 2.8 mol %) (Elless and Rabenhorst, 1994). In contrast, the Al substitution in the hematite of the non-problematic soils was substantially higher, and more variable (ranging from 2.4 to 9.8 mol %), than the problematic soils. Note that one of the non-problematic samples (NP4) did not have sufficient hematite to detect the (110) [hkl]

peak characteristic for the mineral. These results suggest that Al substitution is likely not the cause of the "problematic" nature of PRPM soils.

Table 4.6. Al substitution in hematite of problematic and non-problematic soil samples.

Sample ID	% Mol Al
P1	0.1
P2	0.6
P3	2.0
P4	1.0
P5	1.5
P6	0.1
P7	0.8
P8	0.0
P9	1.0
P10	1.9
P11	0.6
P12	0.2
Mean (SEM)	**0.8 (± 0.2)**
NP1	2.4
NP2	8.0
NP3	9.8
NP4	*no peak
Mean (SEM)	**6.8 (± 2.2)**

Crystallite Size

As previously stated, the crystallite size of minerals has been documented to affect the color of sedimentary deposits and soils. Torrent and Schwertmann (1987) showed a direct relationship between the size of hematite crystals and their color (hue), with larger crystals being more purple in hue (Figure 4.5).

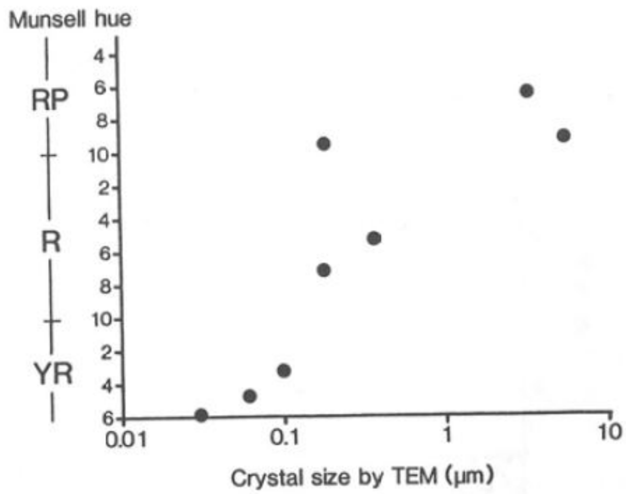

Figure 4.5. *Relationship between Munsell hue and crystal size of eight synthetic hematites. Figure 4-1 from Schwertmann (1993). Data from Torrent and Schwertmann (1987).*

This has also been illustrated by Schwertmann (1993) where larger crystals of synthetic hematites are dark-red to purple in hue (Figure 4.6), and these dark, reddish-purple colors are also similar to that of the colors of the soils and deposits identified as problematic RPM across the U.S. (Chapter 3).

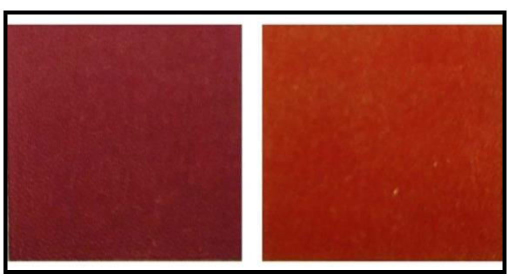
Figure 4.6. *Synthetic hematites with differing crystal sizes (0.4 µm, left; 0.1 µm, right). Larger crystals of hematite are more dark, reddish-purple in color. Figure modified from Schwertmann (1993).*

Furthermore, it has also been demonstrated that larger iron oxide crystals have lower surface area-to-volume ratios that could slow the rate of their reduction relative to smaller crystals. For example, Weidler (1995) reported that the dissolution rate of synthetic goethite was linearly related to the mineral's surface area. If crystal size was the cause of the "problematic nature" of PRPM soils, we would expect to find crystal sizes of hematite in the problematic (low CCPI) samples to be larger than in the non-problematic samples.

Data for the mean crystallite size of hematite calculated from XRD scans of the 5 M NaOH digested clay fractions demonstrate that problematic samples contained significantly larger crystals of hematite than non-problematic samples ($p = 0.0039$, $n=13$) (Table 4.7, Figure 4.7).

Table 4.7. Mean crystallite size of hematite in problematic and non-problematic soil samples.

Sample ID	Mean Crystallize Size (nm)
P1	145
P2	88
P3	94
P4	126
P5	156
P6	94
P7	88
P8	130
P9	150
P10	90
P11	106
P12	90
Mean (SEM)	**113 (± 7.7)**
NP1	69
NP2	45
NP3	56
NP4	*no peak
Mean (SEM)	**57 (± 7.2)**

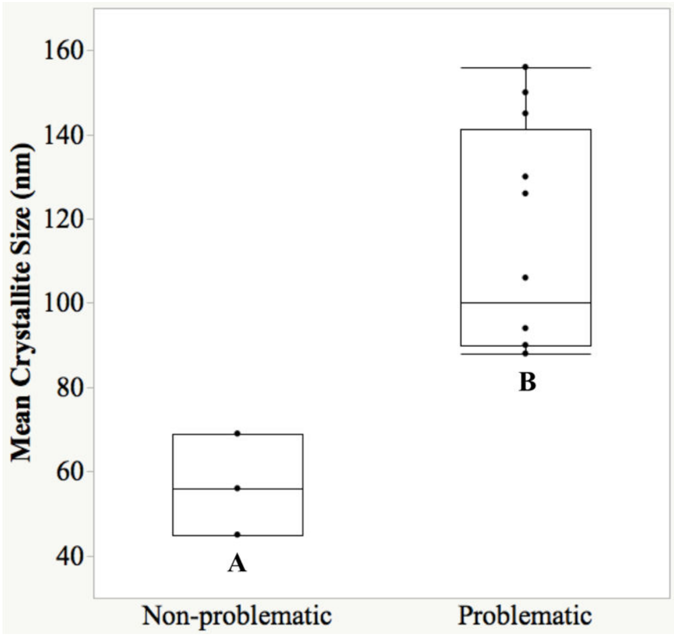

Figure 4.7. *Mean crystallite size (nm) of hematite in problematic and non-problematic soil samples. Group A: Mean = 57 (± 7.7) nm; Group B: Mean = 113 (± 7.2) nm; (p = 0.0039).*

These data suggest that mean crystallite size of hematite is a likely explanation for the "problematic" nature of PRPM soils. These larger crystals that produce the deep, purplish-red colors characteristic of PRPM soils have smaller surface area-to-volume ratios, slowing the rates of chemical reduction. Furthermore, while Al substitution has been shown to impact the shape, size, and color of hematite crystals (Barron and Torrent, 1984; Schwertmann et al., 1979; Stanjek and Schwertmann, 1992; Li et al., 2016), the small amount of Al substitution detected in the samples analyzed suggests that Al substitution does not have a significant impact on the hematite crystal size in these PRPM samples.

Conclusions

Although it had been known that red soils derived from certain RPM are resistant to the development of redoximorphic features, the explanation for their "problematic nature" has been poorly understood. Using 12 problematic and 4 non-problematic soil samples collected from around the country (Chapter 3), three hypotheses for the cause of the “problematic nature” of PRPM soils were examined. Low CCPI values in clay fractions of all PRPM soils demonstrated that the problematic phenomenon cannot be caused by the physical occlusion of Fe oxides within larger-sized (i.e. sand and silt) fractions containing lithic fragments of the red bed, sedimentary parent rocks, thus pointing to a mineralogical cause. The degree of Al for Fe substitution in hematites of the problematic soils was shown to be minimal, leading to the conclusion that Al substitution is not the likely cause for the PRPM phenomenon. By applying the Scherrer equation to XRD scans of hematite in problematic and non-problematic soils, we demonstrated that hematite crystals in the problematic samples were significantly larger ($p = 0.0039$) than those in the non-problematic soils. Therefore, it appears that the larger crystal size, and concomitant lower reactive surface area of the hematite in PRPM soils, is responsible for the “problematic nature” of PRPM soils.

Chapter 5: Conclusions

In order to facilitate better use of the F21 – Red Parent Material (RPM) field indicator, a national, collaborative, hydric soil mapping project was undertaken between the Pedology Laboratory at the University of Maryland, the United States Army Corps of Engineers (USACE), the USDA-Natural Resources Conservation Service (USDA-NRCS), and the Kellogg Soil Survey Laboratory (KSSL). The goal of the project was to identify the occurrence of soils derived from problematic red parent materials (PRPM) using the Color Change Propensity Index (CCPI). During this project, CCPI was determined on ~1200 soil samples from ~450 sites that were collected by field and regulatory personnel from the USACE, USDA-NRCS, KSSL, and other public and private sectors from across the country. CCPI data were then tied to soils and geological mapping units to create RPM guidance maps showing the potential areas where problematic RPM may occur and where the F21 – Red Parent Material field indicator may be appropriately applied.

By these methods, four major RPM regions (e.g. the Northeast and Mid-Atlantic, Great Lakes, South-Central, and the Desert Southwest and Western Mountains) were identified and defined using geological and regional physiographic characteristics across USACE and USDA-NRCS resource areas (e.g. USACE Regional Supplement Regions, USDA-NRCS LRRs and MLRAs). To summarize, problematic RPM in the Northeast and Mid-Atlantic RPM region is characterized mostly by residual and glacial soils derived from dark, red shales, siltstones, sandstones, etc. laid down in passive continental margins during the formation of the current Appalachian mountain system (i.e. the *Paleozoic "Red Beds" of Appalachia;*

the *Glaciated Allegheny Plateau and Catskill Mountains;* and the *Ontario-Erie Plain and Finger Lakes*) and in low lying basins formed during the breakup of supercontinent Pangea (i.e. the *Newark Supergroup*). The Great Lakes RPM region is characterized by dark red, Wisconsinan-aged glacial deposits distributed across the region by the advance and retreat of glacial lobes of the Laurentide ice sheet. These glacial deposits originated from red sedimentary rocks of the Superior Basin (i.e. the *Superior Lobe*; the *Kewaunee Formation*) and some possible Paleozoic/Mesozoic rocks of the Michigan basin (i.e. the *Michigan Basin*). The South-Central RPM region is characterized mostly by residual and alluvial soils derived from Permian-aged bedrock of the Great Plains (i.e. the *Central Red Bed Plains*), and recent alluvial deposits of the Red, Brazos, etc. rivers in southern parts of the Coastal Plain physiographic province (i.e. *Central Red Bed Plains Alluvium*). Finally, the Desert Southwest and Western Mountains RPM region is characterized by residual, colluvial, and alluvial soils derived from dark, red, Paleozoic and Mesozoic-aged rocks uplifted and preserved in the region's mountain ranges (i.e. the *Middle and Southern Rockies*, *Black Hills*, *Arizona and New Mexico Mountains*, *Wasatch and Uinta Mountains*) and the region's various plateaus, canyons, and gorges (i.e. the *Colorado Plateau* and *Pecos River Valley*).

Across these regions, all instances of PRPM were found to be associated with sedimentary, hematite-rich, terrestrial "red bed" formations and the recently deposited (alluvial, colluvial, and glacial) materials derived from them. Most red bed deposits are thought to have formed under similar depositional environments throughout Earth's geologic history when areas on the Earth experienced mass deposition of terrestrial sediments carried from upland sources to near-shore, marginal-marine environments.

In addition to RPM guidance maps, supplemental soils and geological information (as soil series and geologic formations lists), as well as F21 "user notes," (describing PRPM soil characteristics and landforms of occurrence), were also compiled to further aid field practitioners in identifying the occurrence of PRPM soils and in applying the F21 – Red Parent Material field indicator in accompaniment with the RPM guidance maps. Supplemental information and "user notes" also provide information regarding additional data collection needs and where further CCPI analyses may be needed to better identify the occurrence of problematic RPM (despite the comprehensive approach taken to identify the distribution of problematic RPM in this study).

In order to better understand the fundamental cause for the resistance to color change (e.g. the "problematic" nature) of PRPM soils, 12 problematic and 4 non-problematic soil samples were studied from the four major RPM regions identified. Three hypotheses for the cause of the PRPM phenomenon were explored: 1) the physical occlusion of iron oxides within lithified, sedimentary rock fragments in sand and silt fractions; 2) Al for Fe substitution within the crystal structure of hematite; and 3) the crystallite size of hematite, in PRPM soils. Based on CCPI analyses of various particle size fractions (e.g. sands, silts, clays) of problematic and non-problematic RPM soils, it was concluded that physical occlusion was not a viable explanation for the RPM phenomenon, and instead suggests a mineralogical cause. Using X-Ray Diffraction (XRD) techniques to quantify Al for Fe substitution (detected by examining shifts in the (300) [hkl] peak for the mineral hematite), low levels of Al substitution (< 2 mol %) were found within the hematites in the clay fractions of PRPM soils. This suggests that Al for Fe substitution in the hematite is also not a viable explanation for the RPM phenomenon. Finally, mean crystallite sizes of hematite were calculated (using peak broadening of the (110) [hkl] peak for the mineral hematite and applying the Scherrer equation) for both problematic and non-problematic RPM soils. The crystallite size of hematite was significantly larger in the problematic soils than in the non-problematic soils. This suggests that crystal size of hematite is the best possible explanation for the "problematic nature" of PRPM soils.

Overall, data collected, and maps/results produced from this study, should improve hydric soil (and therefore wetland) delineations in areas impacted by problematic RPM across the country. Future research regarding the occurrence of problematic RPM should focus on continuing and refining the occurrence of problematic RPM within the regions and areas specified in this document (predominantly in the Desert Southwest and Western Mountains RPM region). Higher resolution soils and geological datasets, as well as datasets specifically relevant to hydric soils (i.e. USDA-NRCS hydric soils lists, the U.S. Fish and Wildlife Services National Wetlands Inventory Index, etc.), could also be utilized to further refine the RPM guidance maps (and supplemental information) produced during the duration of this study. Since it appears that the cause of PRPM soils is related to the large crystallite sizes of hematite, further work could also explore whether problematic RPM identification might be further constrained or better identified using more specific color requirements (as larger crystals of hematite found in PRPM soils produce rocks and soils that are darker, red in color). Finally, the types of geologic materials identified as PRPM, and larger crystallite sizes of hematite detected in PRPM soils in this study, may also offer some additional understanding regarding the depositional environments and diagenetic processes that lead to the formation of terrestrial red beds.

Appendices

APPENDIX A

The following are copies of original project letters, sampling instructions, and sample data sheets sent to USDA-NRCS and USACE field personnel to solicit for potential problematic RPM soils for the F21 – Red Parent Material hydric soil mapping project.

Department of
ENVIRONMENTAL SCIENCE
& TECHNOLOGY

1213 H. J. Patterson Hall
College Park, MD 20742-5821
Phone 301-405-1343
FAX 301-314-2763

February 6, 2014

TO: NRCS Field Soil Scientists
FROM: Martin C. Rabenhorst; Prof. of Pedology, Sara C. Mack; Grad. Research Asst.
RE: Problematic Red Parent Materials (RPM) Project (Hydric Soils)

Dear Soils Colleague,

We are writing to invite you to participate in what we hope will be a mutually beneficial effort in hydric soil assessment. As you are aware, certain soils can be problematic for hydric soil determinations, for a variety of reasons. Of particular concern to us are soils derived from problematic red parent materials (RPM) that do not develop typical redox features. To address this problem, the "F21 Red Parent Material" hydric soil indicator was developed. Specifically, the F21 indicator should only be invoked in situations where soil parent materials have an inherent resistance to developing hydric soil redox features (the Color Change Propensity Index - CCPI – is used to "prove or disprove" that problematic RPM exist and that F21 can be used). In these situations, the F21 indicator (supported by the CCPI) is often the only useful hydric soil indicator.

Currently, the F21 indicator has been approved in some areas (MLRA 147 and 148 of LRR S and MLRA 127 of LRR N), and is approved everywhere for testing. Preliminary investigations in some states (MN, KS, LA, TX, MD, VA, PA, CT) suggest that the problematic RPMs may be widespread. Mostly, we have observed this phenomenon in soils derived from dark red (Hue 10R to 5YR; V/C usually 4/4 or darker) Mesozoic and Paleozoic sedimentary rocks, and in materials (alluvial, colluvial, glacial) derived from these rocks. Current protocols require that CCPI tests be run on representative soils that can then be tied to particular geological and/or soil series, associations and mapping units. We would like to develop guidance for soil scientists across the country by providing CCPI determination on samples from pedons you think qualify as problematic RPM.

Our intent is to analyze (using CCPI technology) samples from pedons that are representative of soil series, associations or geological map units, and develop guidance maps for the appropriate use of the F21 Red Parent Material Field Indicator of Hydric Soils (FIHS). We are looking to collaborate with field soil scientists who would identify appropriate test sites and collect samples for our analysis. These could be samples from newly targeted sites or also previously-collected/archived samples (Note that we are collaborating with the KSSL). Benefits of participation in the project include obtaining CCPI data on your samples, determining the suitability of using the F21 RPM indicator in your MLRA, leading to improved soil delineation guidance in potential problematic RPM areas.

To participate in the project we would request you provide a morphological description to accompany small (1 pint, sandwich bag size) soil samples from a lithologically representative, potentially problematic RPM pedon of your MLRA, that you collect and ship to us at the University of Maryland College Park. Note that these soils DO NOT have to meet indicator F21. Rather, they only need to be derived from parent materials that you think might be Problematic RPM. In addition to the pedon description, some supporting information would be requested, such as GPS coordinates, series and map unit name, and any relevant geologic information that you could provide.

What we would request from you:

- Some information about the site (series name; map unit name; soil association; geological parent material; lat/long coordinates)
- A soil morphological description
- Small (1 pint – sandwich size bag) samples collected from each horizon described via a small pit or using a bucket auger.

What we would provide to you:

- Results from the CCPI analysis
- Our assessment of whether your soil (and those associated soils formed from related geological materials) would qualify for using Hydric Soil Field Indicator F21.
- Future guidance maps for F21 hydric soil determination in your area

If you believe that there may be problematic RPM issues in your area and are willing to participate in our project, please provide your contact information as described on the next page of this letter and email it to "smack@umd.edu" with the email subject heading and file name "RPM Inquiry – "your name".

We will be in contact with you shortly with additional details regarding site selection, sampling and shipping.

Thank you for your time and consideration. We hope you will join our team!

Sara C. Mack
Dr. Martin C. Rabenhorst
University of Maryland College Park

Red Parent Material (RPM) Project Inquiry Response Form

Thank you for your interest in this problematic red parent material (RPM) project. If you are willing to participate, **please complete and email the information requested below to "smack@umd.edu" with the email subject heading as "RPM Inquiry – "your name"** We will be in contact with you shortly with additional details regarding site selection, sampling and shipping.

Your Name:

Affiliation/Agency:

Title:

Address:

Phone Number:

Email:

Major Land Resource Area(s):

Please Indicate:

_____ I am confident that there are problematic Red Parent Materials in my area(s).

_____ I suspect that there are problematic Red Parent Materials in my areas(s).

_____ I am unsure whether there are problematic Red Parent Materials in my areas(s).

ALSO/OR

_____ I think that some problematic RPM soils may already have been sampled in this area and may be archived at the Kellogg Soil Survey Laboratory.

    _____ Here are the pedon ID numbers:

-
-
-

    _____ I will try to find the pedon ID numbers and will let you know.

Comments or questions:

Thanks again for your interest in this project. We look forward to working with you in assessing potential problematic RPM soils in your area.

Sara C. Mack; Graduate Research Assistant
Dr. Martin C. Rabenhorst; Professor of Pedology
Environmental Science and Technology
University of Maryland

Red Parent Materials (RPM) Project
Soil Sampling Guidance and Information Form

Thank you for joining our RPM project team! The information below provides details regarding documentation, sampling, and shipping. If you have further questions, comments or concerns, please do not hesitate to contact Graduate Research Assistant, Sara C. Mack (smack@umd.edu), at the University of Maryland campus.

SITE SELECTION GUIDANCE

Within your MLRA, consider how many distinctly different geological formations/parent materials occur that you think might be problematic RPM (Note: this could range from a single lithology up to several). Our goal is to obtain samples from one (or possibly two) sites per geologic formation that may be problematic RPM. From previous research, we have determined that RPM phenomenon most likely occurs in soils derived from dark red (Hue 10R to 5YR and V/C 4/4 or darker) Mesozoic and Paleozoic sedimentary rocks, and in transported materials (alluvium, colluvium, and glacial) derived from these rocks. Site information should be recorded using the form below, and then sent with the soil samples.

SOIL MORPHOLOGICAL DESCRIPTION

By using a small pit or a bucket auger, identify the major soil horizons and then describe the properties of those horizons as you would typically do when collecting information for a soil field note (Schoeneberger et al, 2012)[1]. We would ask at a minimum that you include Horizon Name, Horizon Depth (cm), Field Texture, Matrix color, Abundance (estimated %), color and contrast of any redoximorphic features.

COLLECTING SOIL SAMPLES

Soil samples should be collected **from each horizon described**. Small samples (1 pint- small sandwich bag sized) are all that are needed (do not send large samples). If you are able to air dry the samples before you ship them, that is preferred, but not required.

SAMPLE LABELING SCHEME

Each sample bag should be clearly labeled as follows: MLRA-pedon#-Horizon-Depth (cm)
Example: 148 – 01 – Ap – 0 to 25 cm;
148 – 01 – Bt2 – 50 to 75 cm

Each sample bag should be DOUBLE LABELED as follows:

- The number can be written on the outside of the sample bag using a permanent marker
- The number should be written on a piece of paper or card stock using a graphite (lead) pencil and the paper then placed inside the bag (which should then be zip-locked.)

[1] Schoeneberger, P. J., Wysocki, D. A., Benham, E. C. & Staff, S. S. 2012. *Field book for describing and sampling soils, Version 3.0.*, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

SOIL SAMPLE INFORMATION FORM
(please provide the information listed below)

- **Your Name:**
- **Affiliation/Agency:**
- **Field Party/Crew Member Names:**
- **Latitude/Longitude coordinates (decimal degrees preferred):**
- **Date of Sampling:**
- **Soil Map Unit Name and Symbol (SSURGO/Web Soil Survey):**
- **Major Land Resource Area (MLRA):**
- **Parent Material Type (alluvium, glacial till, etc.)**
- **Geologic Source of Parent Material (any geologic information you can provide – geologic age/period, formation name, rock type, etc):**
- **Soil Series (your best assessment):**
- **What other soil series are associated with (formed from) this same lithology:**
- **Brief site description (geomorphological and landscape setting of site):**
- **Number of horizons described/sampled:**

For each pedon description, at a minimum, please provide the following information:

- **Horizon Name**
- **Horizon Depth (cm)**
- **Field Texture**
- **Matrix color**
- **Abundance (estimated %), color, contrast of any redoximorphic features**

Note: more complete morphological descriptions are welcome

<u>SHIPPING OF SAMPLES</u>

Please ship this completed form, with your pedon description and all of your labeled soil samples to:

Pedology Research Laboratory
c/o Sara Mack/Rabenhorst
University of Maryland
Dept. ENST
Bldg 142, Dock H
College Park, MD 20742-2315

Thanks again for your help in getting our RPM project underway! Data from the Color Change Propensity Index (CCPI) analyses and feedback on the RPM will be provided as it becomes available.

Sincerely,

Sara C. Mack, Graduate Research Assistant
Dr. Martin C. Rabenhorst, Professor of Pedology

<u>Red Parent Materials (RPM) Project Sample Information Sheet</u>
Please ship this completed information form with your soil samples.

SHIP TO:
Sara Mack/Rabenhorst
RPM Project
Univ. of MD, ENST
Bldg 142, Dock H
College Park, MD 20742

Your Name	
Affiliation/Agency	

Major Land Resource Area (MLRA)	
Date of Sampling	

Field Party/Crew Members	
Latitude/Longitude Coordinates (decimal degrees preferred)	
Soil Map Unit Name and Symbol (SSURGO/Web Soil Survey)	
Parent Material Type (alluvium, glacial till, etc.).	
Geologic Source of Parent Material (any geologic information you can provide – geologic age/period, formation name, rock type, etc.).	
Soil Series (your best assessment)	
Other soil series associated with (formed from) this same lithology	
Brief Site Description (geomorphological and landscape setting of site)	

Horizon Name	Horizon Depth (cm)	Field Texture	Matrix Color	Redoximorphic Features		
				Abundance (%)	Color	Contrast

UNIVERSITY OF MARYLAND 1856
Department of
ENVIRONMENTAL SCIENCE
& TECHNOLOGY

1213 H. J. Patterson Hall
College Park, MD 20742-5821
Phone 301-405-1343
FAX 301-314-2763

April 27, 2015

TO: USACE Field Scientists

FROM: Martin C. Rabenhorst; Prof. of Pedology
Sara C. Mack; Grad. Research Asst.
Jacob Berkowitz, USACE, ERDC

RE: Problematic Red Parent Materials (RPM) Project (Hydric Soils)

Dear Colleagues,

We are writing to invite you to participate in a mutually beneficial effort to improve hydric soil assessment and wetland delineation in a collaboration between the University of Maryland and the US Army Corps of Engineers Engineer Research and Development Center. As you are aware, certain soils can be problematic for hydric soil determinations, for a variety of reasons. Of particular concern are soils derived from problematic "red parent materials (RPM)" that do not develop typical redox features. To address this problem, the "F21 Red Parent Material" hydric soil indicator was developed. Specifically; however, the F21 indicator should only be invoked in situations where soil parent materials have an inherent resistance to developing hydric soil redox features. This resistance is measured with a Color Change Propensity Index (CCPI) (i.e. a laboratory analysis that can "prove or disprove" that problematic RPM exist and that F21 can be used on soils in a particular area). In these problematic situations, the F21 indicator (supported by the CCPI) is often the only useful hydric soil indicator.

Currently, the F21 indicator has been approved in some areas (MLRA 147 and 148 of LRR S and MLRA 127 of LRR N), and is **approved everywhere for testing**. Preliminary investigations in some states (MN, KS, LA, TX, MD, VA, PA, CT) suggest that these problematic RPMs may be widespread. Mostly, we have observed this phenomenon in soils derived from dark red (Hue 10R to 5YR; V/C usually 4/4 or darker) Mesozoic and Paleozoic sedimentary rocks, and in materials (alluvial, colluvial, glacial) derived from these rocks. Current protocols require that CCPI tests be run on representative soils that can then be tied to particular geological and/or soil series, associations and mapping units. **We would like to develop guidance for field scientists across the country by providing CCPI determination on samples from pedons you think might qualify as problematic RPM.**

Our intent is to analyze (using CCPI technology) samples from pedons that are representative of soil series, associations or geological map units, and develop guidance maps for the appropriate use of the F21 Red Parent Material Field Indicator of Hydric Soils (FIHS). We are looking to collaborate with field scientists who would identify appropriate test sites and collect samples that we would analyze. These could be samples from newly targeted sites or also previously-collected/archived samples. Benefits of participation in the project include obtaining CCPI data on your samples, determining the suitability of using the F21 RPM indicator in your area, and therefore leading to improved soil delineation guidance in potential problematic RPM areas.

To participate in the project we request you provide small (1 pint, sandwich bag size) soil samples from a representative, potentially problematic RPM soil profile of your area, that you collect and ship to us at the University of Maryland College Park. We will provide pre-paid FedEx labels for shipping costs.

Note that **these soils DO NOT have to meet indicator F21**. Rather, they only need to be derived from parent materials that you think might be Problematic RPM. In addition to the soil samples, we would need a brief soil description (similar to wetland delineation data form), and some supporting information, such as GPS coordinates, series and map unit name (if you know this), and any relevant geologic information that you could provide, would be requested.

What we would request from you:

- Some information about the site (series name; map unit name; soil association; geological parent material; lat/long coordinates)
- A soil morphological description (NOTE: a form will be provided for gathering this information)
- Small (1 pint – sandwich size bag) samples collected from each horizon described via a small pit or using a bucket auger. (NOTE: we are primarily interested in the upper 50-100 cm, so this does not need to be a deep excavation.)

What we would provide to you:

- Results from the CCPI analysis
- Our assessment of whether your soil (and those associated soils formed from related geological materials) would qualify for using Hydric Soil Field Indicator F21.
- Future guidance maps for F21 hydric soil determination in your area

If you believe that there may be problematic RPM issues in your area and are willing to participate in our project, please provide your contact information as described on the next page of this letter and email it to "smack@umd.edu" with the email subject heading and file name "RPM Inquiry – "your name".

We will in turn send you a "kit" that includes sampling instructions, description/sample recording forms, sample bags, and shipping instructions with prepaid shipping materials.

Thank you for your time and consideration. We hope you will join our team!

Sara C. Mack
Dr. Martin C. Rabenhorst
University of Maryland College Park

Red Parent Material (RPM) Project Inquiry Response Form

Thank you for your interest in this problematic red parent material (RPM) project. If you are willing to participate, **please complete and email the information requested below to "smack@umd.edu" with the email subject heading as "RPM Inquiry – "your name"** We will be in contact with you shortly with additional details regarding site selection, sampling and shipping.

Your Name:

Affiliation/Agency:

Title:

Address:

Phone Number:

Email:

Major Land Resource Area(s)/USACE District:

Please Indicate:

_____ I am confident that there are problematic Red Parent Materials in my area(s).

_____ I suspect that there are problematic Red Parent Materials in my areas(s).

_____ I am unsure whether there are problematic Red Parent Materials in my areas(s).

Comments or questions:

Thanks again for your interest in this project. We look forward to working with you in assessing potential problematic RPM soils in your area.

Sara C. Mack; Graduate Research Assistant smack@umd.edu
Dr. Martin C. Rabenhorst; Professor of Pedology
Environmental Science and Technology
University of Maryland

Red Parent Materials (RPM) Project
Soil Sampling and Shipping Instructions

Thank you for joining our RPM team! Below are sample collection and shipment instructions. A small sampling/shipping "kit" has been provided to assist you. Within your kit, you should have: 5 small sample bags, a sampling instruction and recording sheet, 5 pieces of labeling card stock, and a sample return package w/ label.

Soil Sampling Instructions:

1. Using a small pit or a bucket auger, identify the major soil horizons (or layers) of your selected pedon to a depth of at least 50 cm (**1 m is preferred**).

2. Describe the properties of the horizons (or layers) on the sample recording sheet provided. We ask at a minimum that you include Horizon Name, Horizon (or layer) Depth (cm), Field Texture, Munsell Matrix Color, and Abundance (estimated %), color and contrast of any redoximorphic features for each horizon (or layer) identified. More detailed pedon descriptions are welcome.

3. Collect a **small (1-pint)** sample from **each horizon (or layer) described** (Fill up bags ONLY half-way, please do not send large samples). Each sample bag should be clearly **DOUBLE** labeled as follows:

   Site# - pedon# - Horizon (or layer) - Depth (cm).
   Example:
   Site#01 – 01 – Ap – 0 to 25 cm;
   Site#01 – 01 – Bt2 – 50 to 75 cm

- The label should be written on the outside of the sample bag using a permanent marker AND on a piece of paper or card stock using a graphite (lead) pencil and the paper then be placed inside the bag.

4. Record the additional pedon information (GPS coordinates, brief site description, geology, etc.) requested on the sample recording sheet provided.

5. Ship all soil samples and recording sheets together in the return package (w/ label) provided to:

   Pedology Research Laboratory
   c/o Sara Mack/Rabenhorst
   University of Maryland
   Dept. ENST
   Bldg 142, Dock H
   College Park, MD 20742-2315

If you are able to air dry soil samples before you ship them, that is preferred, but not required.

Thanks again for joining our RPM project team! If you have further questions, comments or concerns, please contact Graduate Research Assistant, Sara C. Mack (smack@umd.edu), at the University of Maryland campus.

Sincerely,
Sara C. Mack, Graduate Research Assistant
Dr. Martin C. Rabenhorst, Professor of Pedology

Red Parent Materials (RPM) Project Sample Information Sheet

Please ship this completed information form with your soil samples.

SHIP TO:
Sara Mack/Rabenhorst
RPM Project
Univ. of MD, ENST
Bldg 142, Dock H
College Park, MD 20742

Your Name	
Affiliation/Agency	

Site Number	
Date of Sampling	

Field Party/Crew Members	
Latitude/Longitude Coordinates (decimal degrees preferred)	
Soil Map Unit Name and Symbol (SSURGO/Web Soil Survey)	
Parent Material Type (alluvium, glacial till, etc.).	
Geologic Source of Parent Material (any geologic information you can provide – geologic age/period, formation name, rock type, etc.).	
Soil Series (If you know...)	
Other soil series associated with or formed from this same lithology (If you know....)	
Brief Site Description (geomorphological and landscape setting of site)	

Soil Description

	Matrix		Redox Features					
Depth (cm/in) [please specify]	**Color (moist)**	**%**	**Color (moist)**	**%**	**Type[1]**	**Loc[2]**	**Texture**	**Remarks (Provide horizon name if you know)**

[1]Type: C= Concentration, D=Depletion, RM=Reduced Matrix, CS=Covered or Coated Sand Grains

[2]Location: PL=Pore Lining, M=Matrix

APPENDIX B

The following table in Appendix B contains raw data for all soil samples analyzed for their Color Change Propensity Index (CCPI) during this project. Samples quarantined by the Kellogg Soil Survey Laboratory (KSSL) following Plant Protection and Quarantine (PPQ) regulations in accordance with the USDA Animal and Plant Health Inspection Service (APHIS) are also indicated. General information on the USDA-APHIS PPQ program and permitting processes is available on the USDA-NRCS website (*https://www.aphis.usda.gov/plant_health).* Descriptions and acronyms for the columns and values in the table are as follows:

RPM Region - The RPM Region the soil sample(s) belong to as defined in this report ("DS&RM" = Desert Southwest & Western Mountains, "SC" = South-Central", "GL" = Great Lakes, and “MA” = Northeast & Mid-Atlantic).

Geol Grp – The group of soil and parent materials the soil sample(s) belong to, specific to the RPM regions as defined in this document (“AZNM” = Arizona & New Mexico Mountains, “FCM” = Colorado Plateaus, “MOUN” = Middle and Southern Rocky Mountains, “PECO” = Pecos River Valley, “GTGL-G” = Kewaunee Formation, “GTGL-M” = Michigan Basin, “GTGL-S” = Superior Lobe, “GTGL-R” = Rainy Lobe [described with Superior Lobe], “APS” = Paleozoic Red Beds of Appalachia, “GTCM” = Glaciated Allegheny Plateau and Catskill Mountains, “NWS” = Newark Supergroup, “NYLAC” = Ontario-Erie Plain and Finger Lakes, “PRBB” = Central Red Bed Plains, “PRBA-RA“

= Red and Arkansas Rivers, “PRBA-BC” = Brazos and Colorado Rivers, and “HSG” = soil samples collected from the state of HI.

State – The U.S. state the soil sample(s) were collected from.

Series – The USDA-Natural Resource Conservation Service (USDA-NRCS) soil series the soil sample(s) were indicated to “best represent” by project participants who sent samples, the National Cooperative Soil Survey (NCSS) database/Kellogg Soil Survey Laboratory (KSSL), or through correlation using Web Soil Survey.

Pedon_ID – The pedon identification number given to the soil sample(s) for use in this research.

KSSL# = The “Lab Pedon Number” of the soil sampled in the NCSS database, as archived by the KSSL (*https://ncsslabdatamart.sc.egov.usda.gov/querypage.aspx*).

Mean CCPI = The mean CCPI value calculated for all soil samples analyzed for CCPI from a specific pedon sampled.

CCPI Prob? = The CCPI group the pedon was categorized in following classes defined in Rabenhorst and Parikh (2000). (“Yes” = problematic with CCPI < 30, “Uns” = questionable with 30 < CCPI < 40, and “No” = non-problematic with CCPI > 40).

Hor, Depth = Horizon name and depth (cm) designated for pedon sampled.

H, V, C = Moist [Munsell] Color (Hue, Value, and Chroma) measured for the sample prior to CCPI treatment with sodium dithionite (i.e. initially after saturation with citrate buffer solution [no sodium dithionite added] at room temperature [25° C]).

CCPI 01 = CCPI value calculated for the individual soil sample analyzed from a specific pedon. Value was used to calculate the mean CCPI value for the entire pedon sampled (2 to 3 horizons).

MLRA = The Major Land Resource Area (MLRA) the sample belongs to, if indicated by project participants, the NCSS database, KSSL, etc.

APHIS = Indicates if the soil sample(s) were PPQ heat treated prior to shipment from the KSSL ("Reg" = heat treated, "Unreg" = not heat treated).

RPM Region	Geol Grp	State	Series	Pedon ID	KSSL#	Mean CCPI	CCPI Prob?	Hor	Depth	H	H	V	C	CCPI 01	MLRA	APHIS
DS&RM	AZNM	AZ	Contention	Contention_01_SM_k	95P0604	15.8	Yes	A/Bky	0-20	4.9	YR	4.0	3.1	17.5	-	Unreg
DS&RM	AZNM	AZ	Contention	Contention_01_SM_k	95P0604	15.8	Yes	Bky2	40-60	4.8	YR	4.1	3.2	18.0	-	Unreg
DS&RM	AZNM	AZ	Contention	Contention_01_SM_k	95P0604	15.8	Yes	Bssky	80-100	4.8	YR	3.9	3.0	11.8	-	Unreg
DS&RM	AZNM	AZ	White House	White House_01_SM_k	40A3559	38.1	Uns	Bt	5-20	6.0	YR	3.8	3.2	47.7	-	Unreg
DS&RM	AZNM	AZ	White House	White House_01_SM_k	40A3559	38.1	Uns	B2	20-43	5.8	YR	3.9	3.4	34.5	-	Unreg
DS&RM	AZNM	AZ	White House	White House_01_SM_k	40A3559	38.1	Uns	Btk2	79-100	5.6	YR	4.0	3.5	32.2	-	Unreg
DS&RM	AZNM	NM	Peralta	Peralta_01_JR	-	23.9	Yes	A	0-5	5.1	YR	3.6	2.6	26.0	-	-
DS&RM	AZNM	NM	Peralta	Peralta_01_JR	-	23.9	Yes	B1	5-71	4.3	YR	3.7	3.2	21.9	-	-
DS&RM	AZNM	NM	Peralta	Peralta_01_JR	-	23.9	Yes	B2	71-91	4.5	YR	3.8	3.0	23.7	-	-
DS&RM	AZNM	NM	Peralta	Peralta_02_JR	-	24.9	Yes	A	0-8	6.6	YR	3.4	2.4	22.7	-	-
DS&RM	AZNM	NM	Peralta	Peralta_02_JR	-	24.9	Yes	C1	8-66	5.1	YR	3.4	3.0	26.5	-	-
DS&RM	FCM	AR	Moenkopie	Moenkopie_01_k	75C0028	22.5	Yes	A1	0-8	5.7	YR	2.9	3.0	22.2	35	Unreg
DS&RM	FCM	AR	Moenkopie	Moenkopie_01_k	75C0028	22.5	Yes	A2	8-26	4.8	YR	3.4	3.4	21.5	35	Unreg
DS&RM	FCM	AR	Moenkopie	Moenkopie_01_k	75C0028	22.5	Yes	C	26-48	4.7	YR	3.7	3.5	23.8	35	Unreg
DS&RM	FCM	AZ	Arntz	Arntz_01_k	86P0498	15.3	Yes	Bw2	18-30	3.6	YR	3.7	3.7	16.1	35	Unreg
DS&RM	FCM	AZ	Arntz	Arntz_01_k	86P0498	15.3	Yes	2By2	51-71	4.4	YR	3.6	3.3	15.2	35	Unreg
DS&RM	FCM	AZ	Arntz	Arntz_01_k	86P0498	15.3	Yes	4Cry	99-124	3.6	YR	3.5	3.4	14.7	35	Unreg
DS&RM	FCM	AZ	Barx	Barx_01_k	86P0494	20.5	Yes	Bt1	15-25	5.4	YR	3.2	3.0	24.0	35	Unreg
DS&RM	FCM	AZ	Barx	Barx_01_k	86P0494	20.5	Yes	Btk1	38-56	4.5	YR	3.5	3.3	18.8	35	Unreg
DS&RM	FCM	AZ	Barx	Barx_01_k	86P0494	20.5	Yes	Bk	109-135	5.0	YR	3.6	3.4	18.6	35	Unreg
DS&RM	FCM	AZ	Begay	Begay_03_k	82P0880	29.3	Yes	Bw	10-18	6.2	YR	3.9	3.3	28.6	-	Unreg
DS&RM	FCM	AZ	Begay	Begay_03_k	82P0880	29.3	Yes	Bk3	51-69	6.3	YR	4.4	3.6	28.4	-	Unreg
DS&RM	FCM	AZ	Begay	Begay_03_k	82P0880	29.3	Yes	Bk5	109-145	6.6	YR	4.2	3.7	30.8	-	Unreg
DS&RM	FCM	AZ	Boysag	Boysag_01_k	82P0871	37.3	Uns	Bt1	8-25	5.0	YR	4.1	3.9	20.6	35	Unreg
DS&RM	FCM	AZ	Boysag	Boysag_01_k	82P0871	37.3	Uns	Bt2	25-36	5.8	YR	4.6	3.9	54.0	35	Unreg
DS&RM	FCM	AZ	Brinkerhoff	Brinkerhoff_01_k	82P0877	32.2	Uns	Bt	10-30	5.4	YR	3.3	3.3	31.6	35	Unreg
DS&RM	FCM	AZ	Brinkerhoff	Brinkerhoff_01_k	82P0877	32.2	Uns	Bk2	43-56	5.8	YR	3.8	3.9	33.0	35	Unreg
DS&RM	FCM	AZ	Brinkerhoff	Brinkerhoff_01_k	82P0877	32.2	Uns	2Bky	71-127	6.2	YR	4.1	3.6	32.2	35	Unreg
DS&RM	FCM	AZ	Burnswick	Burnwick_01_k	40A0685	7.8	Yes	A2	11-30	4.8	YR	3.8	2.1	8.9	35	Unreg
DS&RM	FCM	AZ	Burnswick	Burnwick_01_k	40A0685	7.8	Yes	C2	58-88	4.9	YR	4.0	1.9	6.7	35	Unreg
DS&RM	FCM	AZ	Epikom	Epikom_01_k	40A0682	14.5	Yes	A	0-8	4.6	YR	3.4	3.3	14.8	35	Unreg
DS&RM	FCM	AZ	Epikom	Epikom_01_k	40A0682	14.5	Yes	C	8-35	4.8	YR	3.4	3.5	14.2	35	Unreg
DS&RM	FCM	AZ	Hagerman	Hagerman_01_k	82P0879	22.6	Yes	Bt	5-20	4.3	YR	3.5	3.6	25.3	35	Unreg
DS&RM	FCM	AZ	Hagerman	Hagerman_01_k	82P0879	22.6	Yes	Btk3	33-51	4.9	YR	4.0	4.2	26.1	35	Unreg
DS&RM	FCM	AZ	Hagerman	Hagerman_01_k	82P0879	22.6	Yes	Btk5	71-81	4.3	YR	3.3	3.5	16.3	35	Unreg
DS&RM	FCM	AZ	Jocity	Jocity_01_k	40A0680	9.7	Yes	A2	8-23	5.3	YR	3.5	2.0	11.6	35	Unreg
DS&RM	FCM	AZ	Jocity	Jocity_01_k	40A0680	9.7	Yes	C2	76-120	6.2	YR	3.5	1.5	7.8	35	Unreg
DS&RM	FCM	AZ	Leanto	Leanto_01_k	86P0496	20.9	Yes	Bw	5-15	4.8	YR	3.5	3.3	18.8	35	Unreg

DS&RM	FCM	AZ	Leanto	Leanto_01_k	86P0496	20.9	Yes	Bk2	28-36	5.0	YR	4.0	3.5	23.0	35	Unreg
DS&RM	FCM	AZ	Mespun	Mespun_01_k	82P0870	27.9	Yes	Bw2	23-46	5.1	YR	3.6	4.1	30.4	35	Unreg
DS&RM	FCM	AZ	Mespun	Mespun_01_k	82P0870	27.9	Yes	C2	84-117	5.0	YR	3.6	4.1	25.4	35	Unreg
DS&RM	FCM	AZ	Mespun	unnamed_21_k	03N0866	40.7	No	C2	10-30	6.4	YR	3.9	3.8	35.3	-	Unreg
DS&RM	FCM	AZ	Mespun	unnamed_21_k	03N0866	40.7	No	C3	30-58	6.0	YR	3.9	3.9	41.1	-	Unreg
DS&RM	FCM	AZ	Mespun	unnamed_21_k	03N0866	40.7	No	2Ckn	58-102	7.2	YR	4.1	3.2	45.8	-	Unreg
DS&RM	FCM	AZ	Mespun	unnamed_19_k	03N0867	38.6	Uns	Bw	5-28	5.5	YR	3.6	3.7	33.6	-	Unreg
DS&RM	FCM	AZ	Mespun	unnamed_19_k	03N0867	38.6	Uns	Ckn	64-84	5.6	YR	4.1	4.2	43.6	-	Unreg
DS&RM	FCM	AZ	Mokaac	Mokaac_01_k	90P0212	31.4	Uns	Bk	8-25	7.1	YR	3.9	3.5	27.7	-	Unreg
DS&RM	FCM	AZ	Mokaac	Mokaac_01_k	90P0212	31.4	Uns	By1	25-66	7.4	YR	4.3	3.7	36.6	-	Unreg
DS&RM	FCM	AZ	Mokaac	Mokaac_01_k	90P0212	31.4	Uns	By3	81-104	7.1	YR	4.2	3.8	29.9	-	Unreg
DS&RM	FCM	AZ	Monue	Monue_01_k	82P0889	21.9	Yes	Bw	5-33	5.7	YR	3.5	3.2	20.6	-	Unreg
DS&RM	FCM	AZ	Monue	Monue_01_k	82P0889	21.9	Yes	Bk	33-51	6.6	YR	3.8	3.0	19.0	-	Unreg
DS&RM	FCM	AZ	Monue	Monue_01_k	82P0889	21.9	Yes	2Bk2	71-102	5.8	YR	3.9	3.7	26.1	-	Unreg
DS&RM	FCM	AZ	Monue	Monue_02_k	10N0586	17.5	Yes	Bw1	13-74	4.2	YR	3.7	3.7	15.9	-	Unreg
DS&RM	FCM	AZ	Monue	Monue_02_k	10N0586	17.5	Yes	Bk	109-173	4.6	YR	3.8	3.6	19.1	-	Unreg
DS&RM	FCM	AZ	Nuffel	Nuffel_01_k	40A0687	13.2	Yes	C1	3-31	4.5	YR	3.7	3.0	12.8	35	Unreg
DS&RM	FCM	AZ	Nuffel	Nuffel_01_k	40A0687	13.2	Yes	C3	63-100	4.4	YR	3.7	3.0	13.5	35	Unreg
DS&RM	FCM	AZ	Padilla	Padilla_01_k	86P0492	15.1	Yes	Bt2	15-33	4.4	YR	3.7	2.9	14.9	35	Unreg
DS&RM	FCM	AZ	Padilla	Padilla_01_k	86P0492	15.1	Yes	Btk	56-89	4.2	YR	3.7	2.7	16.0	35	Unreg
DS&RM	FCM	AZ	Padilla	Padilla_01_k	86P0492	15.1	Yes	C	122-165	4.0	YR	3.7	2.6	14.4	35	Unreg
DS&RM	FCM	AZ	Penzance	Penzance_01_k	87P0044	21.7	Yes	Bt2	23-43	5.0	YR	4.1	3.4	22.3	35	Unreg
DS&RM	FCM	AZ	Penzance	Penzance_01_k	87P0044	21.7	Yes	Btk3	74-107	4.4	YR	4.1	3.4	21.0	35	Unreg
DS&RM	FCM	AZ	Sandark	Sandark_01_TF	-	9.1	Yes	A	0-10	6.1	YR	3.5	2.9	10.6	-	-
DS&RM	FCM	AZ	Sandark	Sandark_01_TF	-	9.1	Yes	B	10-40	6.2	YR	3.4	2.6	7.5	-	-
DS&RM	FCM	AZ	Schmutz	Schmutz_01_k	82P0874	18.1	Yes	AB	10-25	5.5	YR	3.7	3.2	18.3	35	Unreg
DS&RM	FCM	AZ	Schmutz	Schmutz_01_k	82P0874	18.1	Yes	By3	66-91	5.2	YR	3.8	3.4	19.9	35	Unreg
DS&RM	FCM	AZ	Schmutz	Schmutz_01_k	82P0874	18.1	Yes	C	152-178	6.7	YR	3.7	3.3	16.2	35	Unreg
DS&RM	FCM	AZ	Tours	Tours_01_k	75C0027	16.0	Yes	A2	13-30	4.7	YR	3.4	2.9	15.5	-	Unreg
DS&RM	FCM	AZ	Tours	Tours_01_k	75C0027	16.0	Yes	C2	51-79	4.4	YR	3.5	3.1	17.0	-	Unreg
DS&RM	FCM	AZ	Tours	Tours_01_k	75C0027	16.0	Yes	C4	102-152	4.0	YR	3.7	3.0	15.6	-	Unreg
DS&RM	FCM	CO	Acree	Acree_01_k	83P0807	36.5	Uns	BA	20-30	6.9	YR	3.4	2.5	44.3	48A	Unreg
DS&RM	FCM	CO	Acree	Acree_01_k	83P0807	36.5	Uns	Bt3	61-76	6.1	YR	3.8	3.5	33.5	48A	Unreg
DS&RM	FCM	CO	Acree	Acree_01_k	83P0807	36.5	Uns	Bk1	99-127	6.5	YR	3.9	3.3	31.7	48A	Unreg
DS&RM	FCM	CO	Burnson	Burnson_01_k	86P0854	44.6	No	Bt1	15-23	7.4	YR	2.9	1.5	49.0	48A	Unreg
DS&RM	FCM	CO	Burnson	Burnson_01_k	86P0854	44.6	No	Bt3	46-66	7.0	YR	4.0	4.2	53.9	48A	Unreg
DS&RM	FCM	CO	Burnson	Burnson_01_k	86P0854	44.6	No	B/C	102-114	8.7	YR	4.2	3.9	31.0	48A	Unreg
DS&RM	FCM	CO	Evpark	Evpark_01_k	01P0077	62.0	No	BAt	9-21	7.2	YR	3.1	2.1	60.1	-	Unreg
DS&RM	FCM	CO	Evpark	Evpark_01_k	01P0077	62.0	No	Bt	21-43	7.5	YR	3.6	3.1	66.6	-	Unreg
DS&RM	FCM	CO	Evpark	Evpark_01_k	01P0077	62.0	No	Btk	43-72	6.9	YR	4.1	4.4	59.4	-	Unreg

DS&RM	FCM	CO	Fruitland	Fruitland_01_k	04N0234	40.6	No	Bw	20-63	8.1	YR	3.9	2.8	36.6	48A	Unreg
DS&RM	FCM	CO	Fruitland	Fruitland_01_k	04N0234	40.6	No	C	63-154	8.4	YR	4.2	3.3	44.6	48A	Unreg
DS&RM	FCM	CO	Hapgood	unnamed_16_k	92P0815	66.7	No	A2	7-30	7.5	YR	2.9	1.7	55.6	48A	Unreg
DS&RM	FCM	CO	Hapgood	unnamed_16_k	92P0815	66.7	No	A32	56-81	7.6	YR	3.1	1.9	53.9	48A	Unreg
DS&RM	FCM	CO	Hapgood	unnamed_16_k	92P0815	66.7	No	Cr	117-129	9.2	YR	5.0	4.6	90.7	48A	Unreg
DS&RM	FCM	CO	Kunz	unnamed_04_k	92P0780	56.9	No	ABt	8-18	6.7	YR	3.2	2.3	41.0	48A	Unreg
DS&RM	FCM	CO	Kunz	unnamed_04_k	92P0780	56.9	No	Bt1	18-40	5.5	YR	3.8	3.8	52.4	48A	Unreg
DS&RM	FCM	CO	Kunz	unnamed_04_k	92P0780	56.9	No	Bk	63-109	8.9	YR	5.9	3.4	77.2	48A	Unreg
DS&RM	FCM	CO	Mack	Mack_01_k	80P0371	29.6	Yes	B	10-18	6.4	YR	3.5	3.2	29.3	35	Unreg
DS&RM	FCM	CO	Mack	Mack_01_k	80P0371	29.6	Yes	Bk1	69-86	6.8	YR	4.9	3.8	29.9	35	Unreg
DS&RM	FCM	CO	Monogram	Monogram_01_k	80P0373	31.5	Uns	B	8-18	5.6	YR	3.5	3.4	31.8	-	Unreg
DS&RM	FCM	CO	Monogram	Monogram_01_k	80P0373	31.5	Uns	Btk	36-51	5.7	YR	4.0	3.7	28.7	-	Unreg
DS&RM	FCM	CO	Monogram	Monogram_01_k	80P0373	31.5	Uns	2Btk1	71-107	7.5	YR	6.1	3.8	34.1	-	Unreg
DS&RM	FCM	CO	Monticello	Monticello_01_k	83P0808	33.1	Uns	BA	23-38	5.5	YR	3.8	3.3	34.5	39	Unreg
DS&RM	FCM	CO	Monticello	Monticello_01_k	83P0808	33.1	Uns	Bt2	61-76	5.3	YR	3.9	3.7	32.7	39	Unreg
DS&RM	FCM	CO	Monticello	Monticello_01_k	83P0808	33.1	Uns	Bk2	97-132	5.5	YR	3.9	3.5	32.2	39	Unreg
DS&RM	FCM	CO	Nortez	Nortez_01_k	83P0805	45.9	No	BA	15-25	6.5	YR	3.3	2.6	43.1	48A	Unreg
DS&RM	FCM	CO	Nortez	Nortez_01_k	83P0805	45.9	No	Bt2	33-51	5.9	YR	3.9	4.1	48.8	48A	Unreg
DS&RM	FCM	CO	unnamed	unnamed_22_k	10N0839	38.5	Uns	Bt1	15-40	9.6	YR	3.2	2.1	40.0	-	Unreg
DS&RM	FCM	CO	unnamed	unnamed_22_k	10N0839	38.5	Uns	Bt2	40-58	9.8	YR	3.5	2.2	36.9	-	Unreg
DS&RM	FCM	CO	Wetherill	Wetherill_01_k	80P0370	29.9	Yes	Btk1	18-48	5.8	YR	3.7	3.2	29.7	36	Unreg
DS&RM	FCM	CO	Wetherill	Wetherill_01_k	80P0370	29.9	Yes	Btk3	79-122	5.3	YR	4.0	3.9	29.8	36	Unreg
DS&RM	FCM	CO	Wetherill	Wetherill_01_k	80P0370	29.9	Yes	Bk2	180-208	5.4	YR	5.0	4.2	30.4	36	Unreg
DS&RM	FCM	NM	Begay	Begay_01_k	88P0754	15.0	Yes	Bw	2-28	1.9	YR	3.7	3.7	14.5	36B	Unreg
DS&RM	FCM	NM	Begay	Begay_01_k	88P0754	15.0	Yes	C2	43-66	1.7	YR	3.7	3.7	15.1	36B	Unreg
DS&RM	FCM	NM	Begay	Begay_01_k	88P0754	15.0	Yes	C5	84-114	1.7	YR	3.7	3.7	15.4	36B	Unreg
DS&RM	FCM	NM	Fortwingate	Fortwingate_01_k	94P0780	15.7	Yes	Bt1	8-20	4.4	YR	3.4	2.2	17.3	39	Unreg
DS&RM	FCM	NM	Fortwingate	Fortwingate_01_k	94P0780	15.7	Yes	Bt2	20-64	3.5	YR	3.7	2.9	14.0	39	Unreg
DS&RM	FCM	NM	Fraguni	Fraguni_01_k	87P0039	44.3	No	Bt1	18-36	6.2	YR	3.1	2.1	41.5	39	Unreg
DS&RM	FCM	NM	Fraguni	Fraguni_01_k	87P0039	44.3	No	Bt3	53-64	5.1	YR	3.8	3.7	36.9	39	Unreg
DS&RM	FCM	NM	Fraguni	Fraguni_01_k	87P0039	44.3	No	2Bt2	79-94	7.5	YR	4.4	3.6	54.4	39	Unreg
DS&RM	FCM	NM	Parkelei	Parkelei_01_k	94P0781	16.1	Yes	Btk1	12-72	3.4	YR	3.6	3.5	16.6	36	Unreg
DS&RM	FCM	NM	Parkelei	Parkelei_01_k	94P0781	16.1	Yes	Btk3	102-160	3.4	YR	3.6	3.4	15.6	36	Unreg
DS&RM	FCM	NM	Regracic	Regracic_01_k	94P0356	17.1	Yes	Bt	5-48	3.4	YR	3.4	3.2	16.3	36	Unreg
DS&RM	FCM	NM	Regracic	Regracic_01_k	94P0356	17.1	Yes	Btk2	79-114	3.0	YR	3.7	3.3	17.2	36	Unreg
DS&RM	FCM	NM	Regracic	Regracic_01_k	94P0356	17.1	Yes	BCk	152-203	4.4	YR	3.5	3.5	17.9	36	Unreg
DS&RM	FCM	NM	Tintero	Tintero_01_k	99P0495	21.5	Yes	Bt2	18-36	6.2	YR	3.9	3.2	21.6	36	Unreg
DS&RM	FCM	NM	Tintero	Tintero_01_k	99P0495	21.5	Yes	Btk2	75-117	6.0	YR	4.0	3.2	21.4	36	Unreg
DS&RM	FCM	NM	Vinton	Vinton_01_k	10N0134	31.1	Uns	Ap2	10-33	7.7	YR	3.7	2.5	25.9	42	Unreg
DS&RM	FCM	NM	Vinton	Vinton_01_k	10N0134	31.1	Uns	C1	45-75	8.2	YR	4.4	3.3	37.4	42	Unreg

DS&RM	FCM	NM	Vinton	Vinton_01_k	10N0134	31.1	Uns	C3	94-110	7.2	YR	4.6	3.6	29.9	42	Unreg
DS&RM	FCM	NV	Land	Land_01_DM_k	80P0228	44.5	No	Bz1	18-25	8.7	YR	4.4	2.9	46.2	30	Unreg
DS&RM	FCM	NV	Land	Land_01_DM_k	80P0228	44.5	No	C2	89-122	8.8	YR	5.0	3.2	42.9	30	Unreg
DS&RM	FCM	UT	Aneth	Aneth_01_k	92P0987	29.4	Yes	A	0-5	5.9	YR	4.1	4.0	29.7	35	Unreg
DS&RM	FCM	UT	Aneth	Aneth_01_k	92P0987	29.4	Yes	Bw1	5-28	5.6	YR	4.0	3.9	29.1	35	Unreg
DS&RM	FCM	UT	Barx	unnamed_05_k	92P0782	31.2	Uns	Bt1	11-24	5.2	YR	3.5	3.5	32.8	35	Unreg
DS&RM	FCM	UT	Barx	unnamed_05_k	92P0782	31.2	Uns	Bk1	52-85	4.9	YR	3.8	3.9	30.6	35	Unreg
DS&RM	FCM	UT	Barx	unnamed_05_k	92P0782	31.2	Uns	Bk3	114-150	5.0	YR	3.9	4.1	30.1	35	Unreg
DS&RM	FCM	UT	Begay	Begay_02_k	06N0162	20.1	Yes	Bw	9-33	5.4	YR	3.5	3.5	13.0	-	Unreg
DS&RM	FCM	UT	Begay	Begay_02_k	06N0162	20.1	Yes	Bk2	68-92	5.3	YR	3.9	3.9	19.4	-	Unreg
DS&RM	FCM	UT	Begay	Begay_02_k	06N0162	20.1	Yes	2C1	148-156	5.4	YR	4.3	4.4	27.8	-	Unreg
DS&RM	FCM	UT	Blackston	Blackston_01_k	92P1018	20.3	Yes	A	0-6	4.1	YR	3.5	4.0	20.0	35	Unreg
DS&RM	FCM	UT	Blackston	Blackston_01_k	92P1018	20.3	Yes	Bw	6-25	3.6	YR	3.6	4.2	20.5	35	Unreg
DS&RM	FCM	UT	Bond	Bond_01_k	69C0183	46.0	No	Bt1	5-10	5.4	YR	3.4	3.3	45.2	-	Unreg
DS&RM	FCM	UT	Bond	Bond_01_k	69C0183	46.0	No	Bt2	10-40	4.9	YR	3.4	3.6	46.7	-	Unreg
DS&RM	FCM	UT	Bond	Bond_02_k	69C0184	32.5	Uns	Bt1	8-15	7.2	YR	2.9	2.6	35.8	-	Unreg
DS&RM	FCM	UT	Bond	Bond_02_k	69C0184	32.5	Uns	Bt2	15-37	5.9	YR	3.1	3.1	29.2	-	Unreg
DS&RM	FCM	UT	Caval	Caval_01_k	70C0053	32.3	Uns	A1	0-28	7.5	YR	2.6	2.1	34.9	35	Unreg
DS&RM	FCM	UT	Caval	Caval_01_k	70C0053	32.3	Uns	C1	61-81	7.3	YR	3.2	2.8	35.1	35	Unreg
DS&RM	FCM	UT	Caval	Caval_01_k	70C0053	32.3	Uns	Bb	102-109	5.9	YR	3.7	4.2	27.0	35	Unreg
DS&RM	FCM	UT	Detra	Detra_01_k	69C0188	53.5	No	Bt1	20-35	7.5	YR	3.1	1.9	62.1	-	Unreg
DS&RM	FCM	UT	Detra	Detra_01_k	69C0188	53.5	No	Bt22	70-112	5.7	YR	3.8	3.8	44.8	-	Unreg
DS&RM	FCM	UT	Gladel	Gladel_01_k	08N0145	25.6	Yes	A	3-12	6.0	YR	3.3	2.8	21.5	-	Unreg
DS&RM	FCM	UT	Gladel	Gladel_01_k	08N0145	25.6	Yes	Bkm	19-26	6.1	YR	4.3	3.8	29.6	-	Unreg
DS&RM	FCM	UT	Grassytrail	Grassytrail_01_k	02N0195	19.9	Yes	Bw	10-28	5.7	YR	3.6	3.2	21.3	34B	Unreg
DS&RM	FCM	UT	Grassytrail	Grassytrail_01_k	02N0195	19.9	Yes	Bk2	48-86	5.6	YR	3.7	3.4	20.1	34B	Unreg
DS&RM	FCM	UT	Grassytrail	Grassytrail_01_k	02N0195	19.9	Yes	Bky2	132-150	5.2	YR	3.4	3.2	18.3	34B	Unreg
DS&RM	FCM	UT	Hadden	Hadden_01_k	84P0845	19.5	Yes	Btn2	13-41	7.0	YR	4.5	3.4	23.2	34B	Unreg
DS&RM	FCM	UT	Hadden	Hadden_01_k	84P0845	19.5	Yes	2Btn	41-61	6.1	YR	4.6	3.4	21.3	34B	Unreg
DS&RM	FCM	UT	Hadden	Hadden_01_k	84P0845	19.5	Yes	3Cr	94-143	7.3	YR	4.1	2.5	14.2	34B	Unreg
DS&RM	FCM	UT	Hillburn	Hillburn_01_k	99P0390	17.2	Yes	A	0-4	3.8	YR	3.5	3.4	20.1	-	Unreg
DS&RM	FCM	UT	Hillburn	Hillburn_01_k	99P0390	17.2	Yes	Bw	4-17	3.7	YR	3.5	3.5	15.8	-	Unreg
DS&RM	FCM	UT	Hillburn	Hillburn_01_k	99P0390	17.2	Yes	Cr	17-37	3.6	YR	3.6	3.6	15.8	-	Unreg
DS&RM	FCM	UT	Hodman	unnamed_15_k	87P0806	36.5	Uns	BA1	20-38	6.6	YR	3.3	2.7	41.3	35	Unreg
DS&RM	FCM	UT	Hodman	unnamed_15_k	87P0806	36.5	Uns	Bt1	74-112	4.8	YR	3.6	3.6	31.7	35	Unreg
DS&RM	FCM	UT	Kolob	Kolob_01_k	70C0055	40.1	No	Bt1	15-25	7.2	YR	3.5	2.5	44.0	-	Unreg
DS&RM	FCM	UT	Kolob	Kolob_01_k	70C0055	40.1	No	Bt22	46-71	7.2	YR	3.9	3.2	37.1	-	Unreg
DS&RM	FCM	UT	Kolob	Kolob_01_k	70C0055	40.1	No	Bt24	99-132	7.0	YR	3.9	3.5	39.2	-	Unreg
DS&RM	FCM	UT	Limeridge	Limeridge_01_k	82P0788	40.8	No	Bw2	8-20	5.1	YR	3.8	4.0	22.4	35	Unreg
DS&RM	FCM	UT	Limeridge	Limeridge_01_k	82P0788	40.8	No	Bk2	28-41	5.0	YR	4.3	4.4	59.3	35	Unreg

DS&RM	FCM	UT	Mellenthin	unnamed_08_k	92P0883	17.1	Yes	A	0-7	5.8	YR	3.3	2.9	17.1	35	Unreg
DS&RM	FCM	UT	Mellenthin	unnamed_12_k	92P0911	25.0	Yes	Bw	5-16	7.9	YR	4.3	3.0	25.4	35	Unreg
DS&RM	FCM	UT	Mellenthin	unnamed_12_k	92P0911	25.0	Yes	Bk	16-38	7.5	YR	3.8	2.7	24.6	35	Unreg
DS&RM	FCM	UT	Mido	Mido_01_k	06N0169	13.6	Yes	A2	2-8	5.9	YR	3.7	3.7	15.7	-	Unreg
DS&RM	FCM	UT	Mido	Mido_01_k	06N0169	13.6	Yes	Bw	8-25	5.6	YR	3.9	3.9	11.5	-	Unreg
DS&RM	FCM	UT	Milok	Milok_01_k	09N1050	29.4	Yes	A2	22-43	5.5	YR	3.8	4.2	30.7	-	Unreg
DS&RM	FCM	UT	Milok	Milok_01_k	09N1050	29.4	Yes	Bk3	88-122	5.5	YR	5.5	4.4	30.3	-	Unreg
DS&RM	FCM	UT	Milok	Milok_01_k	09N1050	29.4	Yes	Cr	143-180	4.7	YR	3.9	4.4	27.3	-	Unreg
DS&RM	FCM	UT	Mivida	Mivida_01_k	82P0785	25.6	Yes	A2	9-19	4.9	YR	3.5	3.8	21.8	-	Unreg
DS&RM	FCM	UT	Mivida	Mivida_01_k	82P0785	25.6	Yes	Bw2	41-56	4.8	YR	4.0	4.0	28.4	-	Unreg
DS&RM	FCM	UT	Mivida	Mivida_01_k	82P0785	25.6	Yes	Bk2	93-133	4.5	YR	4.0	4.3	26.7	-	Unreg
DS&RM	FCM	UT	Mivida	unnamed_20_k	99P0392	22.0	Yes	Bw	1-9	5.0	YR	3.3	3.8	23.0	-	Unreg
DS&RM	FCM	UT	Mivida	unnamed_20_k	99P0392	22.0	Yes	Bk	17-27	4.3	YR	3.6	3.9	20.9	-	Unreg
DS&RM	FCM	UT	Moenkopie	Moenkopie_02_k	92P0788	13.1	Yes	A	0-10	5.1	YR	3.7	3.8	13.5	34	Unreg
DS&RM	FCM	UT	Moenkopie	Moenkopie_02_k	92P0788	13.1	Yes	C1	10-16	3.5	YR	3.9	3.4	12.7	34	Unreg
DS&RM	FCM	UT	Moenkopie	Moenkopie_03_MD	-	11.5	Yes	LFS	0-8	4.8	YR	3.7	4.0	10.0	-	-
DS&RM	FCM	UT	Moenkopie	Moenkopie_03_MD	-	11.5	Yes	FSL	8-27	4.1	YR	4.0	4.1	11.8	-	-
DS&RM	FCM	UT	Moenkopie	Moenkopie_03_MD	-	11.5	Yes	RES	0-8	3.5	YR	3.2	3.7	12.6	-	-
DS&RM	FCM	UT	Moenkopie	unnamed_06_k	92P0787	14.6	Yes	A	0-4	4.8	YR	3.6	3.7	14.4	34	Unreg
DS&RM	FCM	UT	Moenkopie	unnamed_06_k	92P0787	14.6	Yes	C	4-10	4.4	YR	3.7	3.7	14.9	34	Unreg
DS&RM	FCM	UT	Monticello	Monticello_02_k	07N0493	33.3	Uns	Bt1	15-21	6.1	YR	3.4	2.6	33.7	37	Unreg
DS&RM	FCM	UT	Monticello	Monticello_02_k	07N0493	33.3	Uns	Bt3	45-76	5.3	YR	3.8	3.7	32.9	37	Unreg
DS&RM	FCM	UT	Monticello	Monticello_02_k	07N0493	33.3	Uns	Bk2	119-145	5.7	YR	3.7	3.5	33.3	37	Unreg
DS&RM	FCM	UT	Naplene	Naplene_01_k	70C0059	17.7	Yes	C1	18-38	5.5	YR	3.6	2.9	17.6	-	Unreg
DS&RM	FCM	UT	Naplene	Naplene_01_k	70C0059	17.7	Yes	C4	78-99	5.3	YR	3.6	3.0	17.8	-	Unreg
DS&RM	FCM	UT	Palma	Palma_01_k	69C0180	19.5	Yes	Bt1	23-38	4.1	YR	3.4	3.4	17.6	-	Unreg
DS&RM	FCM	UT	Palma	Palma_01_k	69C0180	19.5	Yes	C1	64-81	4.1	YR	3.6	4.0	21.4	-	Unreg
DS&RM	FCM	UT	Redbank	Redbank_01_k	92P1015	38.3	Uns	A	0-5	6.3	YR	4.7	4.0	41.2	35	Unreg
DS&RM	FCM	UT	Redbank	Redbank_01_k	92P1015	38.3	Uns	C1	5-20	6.0	YR	4.2	3.8	35.4	35	Unreg
DS&RM	FCM	UT	Rizno	unnamed_07_k	92P0879	35.8	Uns	Bk	11-24	5.7	YR	4.3	4.4	35.8	35	Unreg
DS&RM	FCM	UT	Rizno	unnamed_10_k	92P1008	26.7	Yes	A	0-2	8.0	YR	3.2	2.2	24.4	35	Unreg
DS&RM	FCM	UT	Rizno	unnamed_10_k	92P1008	26.7	Yes	C	2-6	7.2	YR	3.8	3.0	29.0	35	Unreg
DS&RM	FCM	UT	Rizno	Rizno_01_k	82P0783	25.1	Yes	C1	5-13	5.0	YR	3.4	3.4	25.3	35	Unreg
DS&RM	FCM	UT	Rizno	Rizno_01_k	82P0783	25.1	Yes	C2	13-19	5.0	YR	3.5	3.5	25.0	35	Unreg
DS&RM	FCM	UT	Rizno	unnamed_17_k	92P0891	18.6	Yes	C1	3-7	3.1	YR	3.5	4.2	18.9	35	Unreg
DS&RM	FCM	UT	Rizno	unnamed_17_k	92P0891	18.6	Yes	C2	7-11	3.0	YR	3.5	4.1	18.3	35	Unreg
DS&RM	FCM	UT	Robroost	Robroost_01_k	82P0786	13.8	Yes	By1	3-23	5.3	YR	4.1	3.5	8.9	35	Unreg
DS&RM	FCM	UT	Robroost	Robroost_01_k	82P0786	13.8	Yes	By3	51-86	3.8	YR	3.7	3.9	18.8	35	Unreg
DS&RM	FCM	UT	Robroost	unnamed_11_k	84P0848	25.6	Yes	Bw	5-33	6.6	YR	4.1	3.2	21.2	34B	Unreg
DS&RM	FCM	UT	Robroost	unnamed_11_k	84P0848	25.6	Yes	By2	48-90	9.3	YR	4.9	3.3	30.0	34B	Unreg

DS&RM	FCM	UT	Simel	Simel_01_k	99P0387	12.2	Yes	Bw	1-9	3.7	YR	3.5	3.2	12.3	-	Unreg
DS&RM	FCM	UT	Simel	Simel_01_k	99P0387	12.2	Yes	C	9-16	3.7	YR	3.4	3.1	12.5	-	Unreg
DS&RM	FCM	UT	Simel	Simel_01_k	99P0387	12.2	Yes	Cr	16-33	3.9	YR	3.3	3.1	11.8	-	Unreg
DS&RM	FCM	UT	Skutumpah	unnamed_14_k	87P0807	46.9	No	A2	8-20	6.8	YR	3.2	2.9	50.7	35	Unreg
DS&RM	FCM	UT	Skutumpah	unnamed_14_k	87P0807	46.9	No	B2	48-64	6.8	YR	3.7	3.4	47.8	35	Unreg
DS&RM	FCM	UT	Skutumpah	unnamed_14_k	87P0807	46.9	No	Bt2	91-119	5.0	YR	3.9	4.5	42.3	35	Unreg
DS&RM	FCM	UT	Strych	unnamed_09_k	92P0999	18.4	Yes	Bw2	9-21	4.3	YR	3.3	4.1	14.9	35	Unreg
DS&RM	FCM	UT	Strych	unnamed_09_k	92P0999	18.4	Yes	Bk1	21-70	4.1	YR	4.0	4.7	22.1	35	Unreg
DS&RM	FCM	UT	Strych	unnamed_09_k	92P0999	18.4	Yes	C	122-150	3.6	YR	3.5	4.4	18.3	35	Unreg
DS&RM	FCM	UT	Suwanee	Suwanee_01_k	92P0886	16.0	Yes	A	0-5	5.5	YR	3.4	2.9	13.4	35	Unreg
DS&RM	FCM	UT	Suwanee	Suwanee_01_k	92P0886	16.0	Yes	C	5-27	4.3	YR	3.7	3.7	18.6	35	Unreg
DS&RM	FCM	UT	Tobler	Tobler_01_k	69C0178	18.2	Yes	B1	5-15	3.6	YR	3.3	4.2	16.4	-	Unreg
DS&RM	FCM	UT	Tobler	Tobler_01_k	69C0178	18.2	Yes	C	43-79	3.3	YR	3.5	4.3	20.0	-	Unreg
DS&RM	FCM	UT	unnamed	unnamed_13_k	87P0805	40.1	No	A2	8-18	6.0	YR	3.3	3.6	41.9	35	Unreg
DS&RM	FCM	UT	unnamed	unnamed_13_k	87P0805	40.1	No	Bt2	30-92	5.6	YR	3.3	3.5	32.8	35	Unreg
DS&RM	FCM	UT	unnamed	unnamed_13_k	87P0805	40.1	No	C2	119-152	5.4	YR	3.9	4.6	45.5	35	Unreg
DS&RM	FCM	UT	Walknolls	Walknolls_01_k	80P0503	74.8	No	B	8-18	8.8	YR	4.0	2.7	62.1	34	Unreg
DS&RM	FCM	UT	Walknolls	Walknolls_01_k	80P0503	74.8	No	Bk	18-41	9.8	YR	4.4	3.0	87.5	34	Unreg
DS&RM	FCM	UT	Whitecanyon	Whitecanyon_01_k	08N0147	21.6	Yes	Bw	12-25	5.2	YR	3.6	3.6	19.6	-	Unreg
DS&RM	FCM	UT	Whitecanyon	Whitecanyon_01_k	08N0147	21.6	Yes	BC	25-90	5.3	YR	3.9	4.2	23.6	-	Unreg
DS&RM	FCM	UT	Winkel	Winkel_01_k	70C0047	28.9	Yes	B	6-18	6.4	YR	3.9	3.4	26.6	-	Unreg
DS&RM	FCM	UT	Winkel	Winkel_01_k	70C0047	28.9	Yes	Bk	18-28	6.4	YR	4.0	3.8	31.1	-	Unreg
DS&RM	MOUN	CO	Bernal	Bernal_01_AE	-	15.4	Yes	A	0-40	6.1	YR	2.7	2.1	15.4	49	-
DS&RM	MOUN	CO	Lonetree	Lonetree_01_AE	-	8.2	Yes	A	0-28	4.9	YR	2.7	2.5	11.9	49	-
DS&RM	MOUN	CO	Lonetree	Lonetree_01_AE	-	8.2	Yes	C	28-50	4.5	YR	2.7	2.7	4.5	49	-
DS&RM	MOUN	CO	Redtom	Redtom_01_AE	-	14.8	Yes	B	10-18	6.5	YR	2.5	2.0	14.5	49	-
DS&RM	MOUN	CO	Redtom	Redtom_01_AE	-	14.8	Yes	C	18-50	5.7	YR	2.9	2.7	15.1	49	-
DS&RM	MOUN	CO	Scout	unnamed_03_k	91P1040	21.9	Yes	E1	18-48	5.6	YR	3.7	2.8	22.7	48A	Unreg
DS&RM	MOUN	CO	Scout	unnamed_03_k	91P1040	21.9	Yes	Bw1	76-99	4.4	YR	3.4	3.6	21.1	48A	Unreg
DS&RM	MOUN	UT	Podo	unnamed_18_k	92P1005	22.9	Yes	A	0-3	5.8	YR	3.2	3.0	21.8	35	Unreg
DS&RM	MOUN	UT	Podo	unnamed_18_k	92P1005	22.9	Yes	C	3-11	5.6	YR	3.3	3.1	24.0	35	Unreg
DS&RM	MOUN	WY	Kirtley	Kirtley_01_k	81P0536	61.2	No	B/B1	3-18	5.8	YR	3.2	2.6	62.5	58B	Unreg
DS&RM	MOUN	WY	Kirtley	Kirtley_01_k	81P0536	61.2	No	Bk2	61-79	5.8	YR	3.8	3.8	59.9	58B	Unreg
DS&RM	PECO	NM	Peralta	Peralta_02_JR	-	24.9	Yes	C2	66-91	4.9	YR	3.5	3.0	25.5	-	-
DS&RM	PECO	NM		Unknown NM	-	18.7	Yes			5.3	YR	3.8	3.0	17.1	-	-
DS&RM	PECO	NM		Unknown NM	-	18.7	Yes			5.2	YR	4.0	3.1	18.8	-	-
DS&RM	PECO	NM		Unknown NM	-	18.7	Yes			5.2	YR	3.8	3.2	20.1	-	-
GL	GTGL-G	MI	Emmet	Emmet_01_k	12N7829	29.6	Yes	A/E	18-30	8.0	YR	2.7	1.7	28.7	94B	Unreg
GL	GTGL-G	MI	Emmet	Emmet_01_k	12N7829	29.6	Yes	Bt	51-66	6.6	YR	3.3	3.1	26.3	94B	Unreg
GL	GTGL-G	MI	Emmet	Emmet_01_k	12N7829	29.6	Yes	2Cd1	84-99	6.8	YR	3.8	3.5	34.0	94B	Unreg

GL	GTGL-G	WI	Frechette	Frechette_01_k	97P0187	19.8	Yes	Bw2	18-38	8.3	YR	3.6	3.2	18.1	95A	Unreg
GL	GTGL-G	WI	Frechette	Frechette_01_k	97P0187	19.8	Yes	Bt1/E1	66-94	6.0	YR	3.4	3.2	21.5	95A	Unreg
GL	GTGL-G	WI	Hortonville	Hortonville_01_GL	-	21.1	Yes	Ap	0-28	7.3	YR	3.5	2.3	19.0	95A	-
GL	GTGL-G	WI	Hortonville	Hortonville_01_GL	-	21.1	Yes	Bt1	28-43	5.7	YR	3.9	3.3	22.4	95A	-
GL	GTGL-G	WI	Hortonville	Hortonville_01_GL	-	21.1	Yes	Bt3	61-97	6.1	YR	4.4	3.7	21.9	95A	-
GL	GTGL-G	WI	Keshena	Keshena_01_k	97P0189	20.0	Yes	Bw2	18-30	7.8	YR	3.7	3.0	18.7	95A	Unreg
GL	GTGL-G	WI	Keshena	Keshena_01_k	97P0189	20.0	Yes	E/Bt	30-48	6.9	YR	3.6	3.0	18.3	95A	Unreg
GL	GTGL-G	WI	Keshena	Keshena_01_k	97P0189	20.0	Yes	Bt/E2	76-124	5.2	YR	3.5	3.1	22.9	95A	Unreg
GL	GTGL-G	WI	Manawa	Manawa_01_GL	-	32.3	Yes	Ap	0-25	8.7	YR	3.1	1.2	48.6	95A	-
GL	GTGL-G	WI	Manawa	Manawa_01_GL	-	32.3	Yes	Bt1	25-30	8.9	YR	4.1	2.4	29.2	95A	-
GL	GTGL-G	WI	Manawa	Manawa_01_GL	-	32.3	Yes	Bt3	76-104	5.9	YR	4.4	3.3	19.2	95A	-
GL	GTGL-G	WI	Moshawquit	Moshawquit_01_k	98P0296	27.1	Yes	Bw1	8-18	7.8	YR	3.4	3.2	30.6	95A	Unreg
GL	GTGL-G	WI	Moshawquit	Moshawquit_01_k	98P0296	27.1	Yes	2Bt/E2	99-122	6.9	YR	3.4	3.1	23.6	95A	Unreg
GL	GTGL-G	WI	Onaway	Onaway_01_k	40A1632	19.8	Yes	E	10-20	8.4	YR	3.1	1.9	12.9	95A	Unreg
GL	GTGL-G	WI	Onaway	Onaway_01_k	40A1632	19.8	Yes	Bt	46-61	6.4	YR	3.5	3.2	24.2	95A	Unreg
GL	GTGL-G	WI	Onaway	Onaway_01_k	40A1632	19.8	Yes	C1	72-110	6.4	YR	3.9	3.3	22.2	95A	Unreg
GL	GTGL-G	WI	Poygan	Poygan_01_k	84P0923	25.5	Yes	Bg	25-37	9.0	YR	4.1	3.0	28.3	-	Unreg
GL	GTGL-G	WI	Poygan	Poygan_01_k	84P0923	25.5	Yes	C1	65-100	5.3	YR	4.3	3.4	22.6	-	Unreg
GL	GTGL-G	WI	Symco	Symco_01_k	78P0512	27.2	Yes	Ap	0-28	8.3	YR	2.7	1.2	39.0	90	Unreg
GL	GTGL-G	WI	Symco	Symco_01_k	78P0512	27.2	Yes	Bt1	46-58	6.0	YR	3.6	3.1	21.8	90	Unreg
GL	GTGL-G	WI	Symco	Symco_01_k	78P0512	27.2	Yes	C	79-152	5.5	YR	4.0	3.2	20.7	90	Unreg
GL	GTGL-G	WI	Waymor	Waymor_01_k	40A1672	27.8	Yes	E	18-28	8.7	YR	3.7	2.6	25.3	95A	Unreg
GL	GTGL-G	WI	Waymor	Waymor_01_k	40A1672	27.8	Yes	2Bt12	61-89	7.2	YR	3.8	3.1	27.5	95A	Unreg
GL	GTGL-G	WI	Waymor	Waymor_01_k	40A1672	27.8	Yes	2C1	119-147	7.5	YR	4.4	3.5	30.7	95A	Unreg
GL	GTGL-G	WI	Winneconne	Winneconne_01_GL	-	24.5	Yes	Bt1	18-61	4.6	YR	4.2	3.6	26.0	95A	-
GL	GTGL-G	WI	Winneconne	Winneconne_01_GL	-	24.5	Yes	Bt2	61-79	4.6	YR	4.5	3.6	23.0	95A	-
GL	GTGL-M	MI	Pickford	Pickford_01_k	40A1917	24.4	Yes	B11	23-36	6.9	YR	4.1	3.5	28.2	94B	Unreg
GL	GTGL-M	MI	Pickford	Pickford_01_k	40A1917	24.4	Yes	C2	81-102	7.0	YR	4.3	2.9	20.6	94B	Unreg
GL	GTGL-M	MI	Pickford	Pickford_02_k	91P0140	20.5	Yes	Bw1	12-43	7.7	YR	3.4	2.6	13.1	90A	Unreg
GL	GTGL-M	MI	Pickford	Pickford_02_k	91P0140	20.5	Yes	B/E	84-145	5.7	YR	3.6	3.1	22.7	90A	Unreg
GL	GTGL-M	MI	Pickford	Pickford_02_k	91P0140	20.5	Yes	Cd	213-272	5.5	YR	3.5	3.0	25.7	90A	Unreg
GL	GTGL-R	MN	Brainerd	Brainerd_01_k	82P0067	34.7	Uns	2EB	25-36	8.9	YR	3.8	3.2	38.7	-	Unreg
GL	GTGL-R	MN	Brainerd	Brainerd_01_k	82P0067	34.7	Uns	2Bt1	52-72	7.9	YR	3.3	3.3	34.9	-	Unreg
GL	GTGL-R	MN	Brainerd	Brainerd_01_k	82P0067	34.7	Uns	2CB	90-114	7.4	YR	3.4	3.0	30.6	-	Unreg
GL	GTGL-R	MN	Bugcreek	Bugcreek_01_k	95P0473	48.6	No	Bw1	10-28	8.5	YR	3.1	2.6	35.6	93	Unreg
GL	GTGL-R	MN	Bugcreek	Bugcreek_01_k	95P0473	48.6	No	Bw3	43-61	8.4	YR	2.7	2.4	50.6	93	Unreg
GL	GTGL-R	MN	Bugcreek	Bugcreek_01_k	95P0473	48.6	No	Bw5	102-119	8.2	YR	2.7	3.3	59.5	93	Unreg
GL	GTGL-R	MN	Cloquet	Cloquet_01_k	40A1708	24.2	Yes	Bhs1	8-20	8.3	YR	3.5	2.5	26.3	-	Unreg
GL	GTGL-R	MN	Cloquet	Cloquet_01_k	40A1708	24.2	Yes	2Bt	36-43	7.3	YR	2.8	2.9	32.7	-	Unreg
GL	GTGL-R	MN	Cloquet	Cloquet_01_k	40A1708	24.2	Yes	2C	91-152	9.1	YR	3.0	2.6	13.5	-	Unreg

GL	GTGL-R	MN	Flak	Flak_01_k	82P0719	50.4	No	Ap	0-23	8.7	YR	2.7	1.6	57.9	-	Unreg
GL	GTGL-R	MN	Flak	Flak_01_k	82P0719	50.4	No	Bt1	48-76	8.6	YR	3.6	3.2	48.3	-	Unreg
GL	GTGL-R	MN	Flak	Flak_01_k	82P0719	50.4	No	BC1	104-130	8.7	YR	3.5	3.1	44.9	-	Unreg
GL	GTGL-R	MN	Hulligan	Hulligan_01_k	95P0474	27.3	Yes	Bw1	18-33	7.9	YR	3.2	2.1	23.6	93	Unreg
GL	GTGL-R	MN	Hulligan	Hulligan_01_k	95P0474	27.3	Yes	2C1	56-76	7.7	YR	2.5	2.5	30.9	93	Unreg
GL	GTGL-R	MN	Nokay	Nokay_01_MW_k	82P0068	39.0	Uns	E	11-32	9.7	YR	3.7	2.4	51.3	90	Unreg
GL	GTGL-R	MN	Nokay	Nokay_01_MW_k	82P0068	39.0	Uns	2Bt	53-70	7.8	YR	3.3	3.0	34.6	90	Unreg
GL	GTGL-R	MN	Nokay	Nokay_01_MW_k	82P0068	39.0	Uns	2C1	89-109	7.8	YR	3.2	2.8	31.2	90	Unreg
GL	GTGL-R	MN	Prebish	Prebish_01_MW_k	13N0476	52.0	No	Eg	20-30	9.6	YR	3.5	1.9	78.1	90A	Unreg
GL	GTGL-R	MN	Prebish	Prebish_01_MW_k	13N0476	52.0	No	Bw	77-96	9.4	YR	4.0	3.3	38.2	90A	Unreg
GL	GTGL-R	MN	Prebish	Prebish_01_MW_k	13N0476	52.0	No	2Cd	140-201	8.3	YR	3.9	3.4	39.8	90A	Unreg
GL	GTGL-R	MN	Toimi	Toimi_01_MW	-	34.7	Uns	Bw1	23-70	8.0	YR	3.2	2.6	38.8	93A	-
GL	GTGL-R	MN	Toimi	Toimi_01_MW	-	34.7	Uns	Bw2	70-92	8.3	YR	3.4	2.8	33.2	93A	-
GL	GTGL-R	MN	Toimi	Toimi_01_MW	-	34.7	Uns	2BCd	105-115	8.4	YR	3.1	2.5	32.1	93A	-
GL	GTGL-R	MN	Toimi	Toimi_02_k	95P0472	35.4	Uns	Bw1	23-38	8.2	YR	3.0	2.6	52.0	93	Unreg
GL	GTGL-R	MN	Toimi	Toimi_02_k	95P0472	35.4	Uns	BC	61-89	9.1	YR	3.1	2.4	27.5	93	Unreg
GL	GTGL-R	MN	Toimi	Toimi_02_k	95P0472	35.4	Uns	2Cd1	89-130	9.1	YR	3.1	2.3	26.7	93	Unreg
GL	GTGL-R	MN	unnamed	unnamed_01_k	78P0108	38.3	Uns	Bhs1	10-23	8.4	YR	3.0	2.6	52.3	-	Unreg
GL	GTGL-R	MN	unnamed	unnamed_01_k	78P0108	38.3	Uns	B	38-63	9.5	YR	3.3	3.0	37.2	-	Unreg
GL	GTGL-R	MN	unnamed	unnamed_01_k	78P0108	38.3	Uns	Cx	63-122	0.2	Y	3.2	2.2	25.5	-	Unreg
GL	GTGL-R	MN	unnamed	unnamed_02_k	78P0112	54.2	No	Bhs1	10-22	7.8	YR	2.9	2.3	55.1	-	Unreg
GL	GTGL-R	MN	unnamed	unnamed_02_k	78P0112	54.2	No	B	38-89	9.1	YR	2.9	2.5	53.3	-	Unreg
GL	GTGL-R	WI	Chetek	Chetek_01_k	40A1626	50.0	No	Bt	20-43	8.3	YR	3.3	2.9	51.0	-	Unreg
GL	GTGL-R	WI	Chetek	Chetek_01_k	40A1626	50.0	No	C1	53-86	8.3	YR	3.6	3.3	51.4	-	Unreg
GL	GTGL-R	WI	Chetek	Chetek_01_k	40A1626	50.0	No	C3	135-152	8.7	YR	3.6	3.0	47.7	-	Unreg
GL	GTGL-S	MI	Annalake	Annalake_01_k	02N0152	8.6	Yes	E	7-17	5.4	YR	3.1	2.1	11.6	-	Unreg
GL	GTGL-S	MI	Annalake	Annalake_01_k	02N0152	8.6	Yes	Bs	25-54	5.9	YR	3.2	2.9	6.6	-	Unreg
GL	GTGL-S	MI	Annalake	Annalake_01_k	02N0152	8.6	Yes	BC	54-70	6.0	YR	3.2	2.9	7.7	-	Unreg
GL	GTGL-S	MI	Froberg	Froberg_01_k	03N0267	18.2	Yes	Bt	20-56	3.6	YR	4.0	3.7	20.5	92	Unreg
GL	GTGL-S	MI	Froberg	Froberg_01_k	03N0267	18.2	Yes	2BC2	81-114	3.9	YR	3.5	3.4	17.8	92	Unreg
GL	GTGL-S	MI	Froberg	Froberg_01_k	03N0267	18.2	Yes	3BC4	188-208	3.6	YR	3.8	3.4	16.4	92	Unreg
GL	GTGL-S	MI	Gogebic	Gogebic_01_k	03N0286	11.2	Yes	E	10-23	5.9	YR	3.1	2.0	13.8	-	Unreg
GL	GTGL-S	MI	Gogebic	Gogebic_01_k	03N0286	11.2	Yes	C	138-200	4.9	YR	3.3	2.6	8.7	-	Unreg
GL	GTGL-S	MI	Gull Point	Gull Point_01_k	99P0170	17.4	Yes	A2	15-36	6.9	YR	2.8	1.7	19.7	-	Unreg
GL	GTGL-S	MI	Gull Point	Gull Point_01_k	99P0170	17.4	Yes	2Bt	81-99	4.4	YR	3.8	3.3	15.7	-	Unreg
GL	GTGL-S	MI	Gull Point	Gull Point_01_k	99P0170	17.4	Yes	2BCd1	99-152	3.9	YR	3.9	3.3	16.7	-	Unreg
GL	GTGL-S	MI	Matchwood	Matchwood_01_k	04N0464	23.3	Yes	Bg	10-25	9.4	YR	3.9	2.4	29.6	92	Unreg
GL	GTGL-S	MI	Matchwood	Matchwood_01_k	04N0464	23.3	Yes	Bt	43-74	4.6	YR	4.1	3.8	24.2	92	Unreg
GL	GTGL-S	MI	Matchwood	Matchwood_01_k	04N0464	23.3	Yes	2C1	94-127	4.0	YR	3.9	3.2	16.2	92	Unreg
GL	GTGL-S	MI	Mishwabic	Mishwabic_01_k	05N0197	40.1	Uns	Bw	12-20	8.4	YR	2.1	0.9	71.4	92	Unreg

GL	GTGL-S	MI	Mishwabic	Mishwabic_01_k	05N0197	40.1	Uns	Cd	46-203	4.3	YR	3.5	2.8	8.7	92	Unreg
GL	GTGL-S	MI	Montreal	Montreal_01_k	01P0154	14.0	Yes	E	5-15	7.4	YR	2.9	1.9	8.0	-	Unreg
GL	GTGL-S	MI	Montreal	Montreal_01_k	01P0154	14.0	Yes	E/B	51-84	6.5	YR	3.3	3.0	16.0	-	Unreg
GL	GTGL-S	MI	Montreal	Montreal_01_k	01P0154	14.0	Yes	B/Ex	84-130	6.0	YR	3.5	2.9	17.9	-	Unreg
GL	GTGL-S	MI	Moquah	Moquah_01_k	03N0268	11.0	Yes	A2	5-15	6.0	YR	2.9	2.2	13.3	92	Unreg
GL	GTGL-S	MI	Moquah	Moquah_01_k	03N0268	11.0	Yes	C2	61-104	5.6	YR	3.4	3.0	8.6	92	Unreg
GL	GTGL-S	MI	Moquah	Moquah_02_k	02N0153	12.7	Yes	C1	5-23	5.5	YR	3.1	2.4	12.7	93	Unreg
GL	GTGL-S	MI	Moquah	Moquah_02_k	02N0153	12.7	Yes	C4	65-125	5.8	YR	3.1	2.6	12.8	93	Unreg
GL	GTGL-S	MI	Negwegon	Negwegon_01_k	05N0190	15.7	Yes	B/E	23-46	4.8	YR	4.0	3.0	13.0	92	Unreg
GL	GTGL-S	MI	Negwegon	Negwegon_01_k	05N0190	15.7	Yes	BC	71-147	3.8	YR	4.1	3.5	18.5	92	Unreg
GL	GTGL-S	MI	Nonesuch	Nonesuch_01_k	00P0279	9.4	Yes	E	3-10	4.0	YR	3.2	2.2	10.0	-	Unreg
GL	GTGL-S	MI	Nonesuch	Nonesuch_01_k	00P0279	9.4	Yes	Bt2	41-58	4.8	YR	3.1	2.9	10.4	-	Unreg
GL	GTGL-S	MI	Nonesuch	Nonesuch_01_k	00P0279	9.4	Yes	Crt	86-127	4.4	YR	3.3	2.6	7.9	-	Unreg
GL	GTGL-S	MI	Porkies	Porkies_01_k	03N0266	13.7	Yes	E	8-10	6.0	YR	3.2	2.3	8.9	93	Unreg
GL	GTGL-S	MI	Porkies	Porkies_01_k	03N0266	13.7	Yes	Bt	102-127	5.5	YR	3.1	3.0	18.4	93	Unreg
GL	GTGL-S	MI	Schaat Creek	Schaat Creek_01_k	05N0195	18.5	Yes	C1	13-25	6.5	YR	3.9	2.9	20.4	92	Unreg
GL	GTGL-S	MI	Schaat Creek	Schaat Creek_01_k	05N0195	18.5	Yes	C3	48-109	4.1	YR	4.0	3.4	16.5	92	Unreg
GL	GTGL-S	MI	Spear	Spear_01_k	05N0179	17.3	Yes	E/B	10-36	6.9	YR	4.1	3.1	18.9	92	Unreg
GL	GTGL-S	MI	Spear	Spear_01_k	05N0179	17.3	Yes	B/E2	66-127	4.7	YR	4.2	3.1	15.7	92	Unreg
GL	GTGL-S	MI	Sporley	Sporley_01_k	00P0280	10.8	Yes	E	10-18	5.4	YR	3.3	2.3	9.2	-	Unreg
GL	GTGL-S	MI	Sporley	Sporley_01_k	00P0280	10.8	Yes	B/E	61-94	4.7	YR	3.7	3.2	12.4	-	Unreg
GL	GTGL-S	MI	Trap Falls	Trapfalls_01_k	05N0198	18.4	Yes	Bt1	23-43	4.4	YR	3.8	3.4	18.1	92	Unreg
GL	GTGL-S	MI	Trap Falls	Trapfalls_01_k	05N0198	18.4	Yes	Cd	76-137	3.9	YR	3.9	3.4	18.7	92	Unreg
GL	GTGL-S	MI	Trimountain	Trimountain_01_k	86P0776	14.7	Yes	E	0-10	6.2	YR	2.8	1.8	12.9	93	Unreg
GL	GTGL-S	MI	Trimountain	Trimountain_01_k	86P0776	14.7	Yes	2E/Bx	66-85	4.7	YR	3.7	3.1	15.3	93	Unreg
GL	GTGL-S	MI	Trimountain	Trimountain_01_k	86P0776	14.7	Yes	2BCd	87-116	4.6	YR	3.6	3.4	15.9	93	Unreg
GL	GTGL-S	MN	Ahmeek	Ahmeek_01_MW_k	95P0476	20.3	Yes	Bw1	10-41	6.0	YR	3.3	2.8	22.5	93A	Unreg
GL	GTGL-S	MN	Ahmeek	Ahmeek_01_MW_k	95P0476	20.3	Yes	2Bw3	66-97	5.4	YR	3.2	2.4	17.4	93A	Unreg
GL	GTGL-S	MN	Ahmeek	Ahmeek_01_MW_k	95P0476	20.3	Yes	2C2	168-224	5.5	YR	2.9	2.4	21.0	93A	Unreg
GL	GTGL-S	MN	Ahmeek	Ahmeek_02_MW_k	78P0113	20.2	Yes	B/A	10-18	7.4	YR	2.9	2.0	21.0	93A	Unreg
GL	GTGL-S	MN	Ahmeek	Ahmeek_02_MW_k	78P0113	20.2	Yes	B	33-53	6.9	YR	3.4	2.6	18.3	93A	Unreg
GL	GTGL-S	MN	Ahmeek	Ahmeek_02_MW_k	78P0113	20.2	Yes	Cx2	96-142	6.0	YR	3.2	2.6	21.2	93A	Unreg
GL	GTGL-S	MN	Augustana	Augustana_01_MW	-	23.4	Yes	2Bw	17-45	7.9	YR	2.9	2.5	24.2	93A	-
GL	GTGL-S	MN	Augustana	Augustana_01_MW	-	23.4	Yes	2Bt2	68-85	6.1	YR	3.4	2.5	19.0	93A	-
GL	GTGL-S	MN	Augustana	Augustana_01_MW	-	23.4	Yes	3BCd	85-100	5.4	YR	3.8	3.2	27.1	93A	-
GL	GTGL-S	MN	Ault	Ault_01_k	95P0470	39.5	Uns	BA	13-20	7.8	YR	3.0	1.9	39.5	-	Unreg
GL	GTGL-S	MN	Ault	Ault_01_k	95P0470	39.5	Uns	Bw2	46-69	8.2	YR	3.4	3.3	38.6	-	Unreg
GL	GTGL-S	MN	Ault	Ault_01_k	95P0470	39.5	Uns	BC	91-109	8.9	YR	3.4	2.7	40.4	-	Unreg
GL	GTGL-S	MN	Automba	Automba_01_k	40A1703	26.8	Yes	B1	28-41	7.1	YR	3.4	3.4	28.1	-	Unreg
GL	GTGL-S	MN	Automba	Automba_01_k	40A1703	26.8	Yes	B/A	61-69	5.7	YR	3.4	3.3	24.6	-	Unreg

GL	GTGL-S	MN	Automba	Automba_01_k	40A1703	26.8	Yes	Bt2	81-102	5.5	YR	3.3	3.1	27.7	-	Unreg
GL	GTGL-S	MN	Badriver	Badriver_01_MW_k	12N7625	21.8	Yes	E	13-45	5.6	YR	3.4	2.5	21.6	92	Unreg
GL	GTGL-S	MN	Badriver	Badriver_01_MW_k	12N7625	21.8	Yes	Bt	58-86	3.6	YR	3.6	3.5	22.3	92	Unreg
GL	GTGL-S	MN	Badriver	Badriver_01_MW_k	12N7625	21.8	Yes	Ck	127-203	3.8	YR	3.7	3.4	21.4	92	Unreg
GL	GTGL-S	MN	Brennyville	Brennyville_01_k	97P0265	39.7	Uns	E	18-30	9.5	YR	4.1	2.7	42.3	90	Unreg
GL	GTGL-S	MN	Brennyville	Brennyville_01_k	97P0265	39.7	Uns	2B/E	53-64	8.3	YR	3.8	3.1	45.8	90	Unreg
GL	GTGL-S	MN	Brennyville	Brennyville_01_k	97P0265	39.7	Uns	2BC	97-130	6.8	YR	3.2	2.8	31.0	90	Unreg
GL	GTGL-S	MN	Cuttre	Cuttre_01_MW	-	35.7	Uns	B/E	20-30	4.8	YR	4.1	3.2	39.5	92	-
GL	GTGL-S	MN	Cuttre	Cuttre_01_MW	-	35.7	Uns	Btk2	60-70	4.1	YR	4.3	3.6	36.5	92	-
GL	GTGL-S	MN	Cuttre	Cuttre_01_MW	-	35.7	Uns	BC	150-160	3.6	YR	4.0	3.6	31.0	92	-
GL	GTGL-S	MN	Cuttre	Cuttre_02_MW_k	12N7627	21.0	Yes	B/E	15-20	4.8	YR	3.5	2.6	19.1	92	Unreg
GL	GTGL-S	MN	Cuttre	Cuttre_02_MW_k	12N7627	21.0	Yes	Bk	58-74	4.4	YR	3.7	3.1	22.3	92	Unreg
GL	GTGL-S	MN	Cuttre	Cuttre_02_MW_k	12N7627	21.0	Yes	Css1	74-102	5.4	YR	3.7	2.6	21.6	92	Unreg
GL	GTGL-S	MN	Duluth	Duluth_01_MW_k	97P0224	29.6	Yes	Bw	15-23	7.7	YR	3.7	2.6	32.6	88	Unreg
GL	GTGL-S	MN	Duluth	Duluth_01_MW_k	97P0224	29.6	Yes	2Bt1	41-69	6.7	YR	3.7	2.9	28.1	88	Unreg
GL	GTGL-S	MN	Duluth	Duluth_01_MW_k	97P0224	29.6	Yes	2BC	99-132	6.8	YR	3.7	2.9	28.0	88	Unreg
GL	GTGL-S	MN	Duluth	Duluth_02_k	97P0269	24.7	Yes	E	18-28	7.8	YR	3.6	2.1	22.6	90	Unreg
GL	GTGL-S	MN	Duluth	Duluth_02_k	97P0269	24.7	Yes	Bt1	56-109	7.2	YR	3.5	2.8	26.1	90	Unreg
GL	GTGL-S	MN	Duluth	Duluth_02_k	97P0269	24.7	Yes	C	156-203	7.7	YR	3.6	2.7	25.6	90	Unreg
GL	GTGL-S	MN	Eldes	Eldes_01_k	12N7628	30.1	Uns	A1	0-28	8.0	YR	2.2	1.1	52.0	93	Unreg
GL	GTGL-S	MN	Eldes	Eldes_01_k	12N7628	30.1	Uns	Bw1	51-68	8.0	YR	3.1	2.3	17.8	93	Unreg
GL	GTGL-S	MN	Eldes	Eldes_01_k	12N7628	30.1	Uns	2C1	86-127	4.7	YR	3.4	3.1	20.5	93	Unreg
GL	GTGL-S	MN	Ellsburg	Ellsburg_01_MW	-	33.1	Uns	E	15-28	8.6	YR	4.1	3.0	34.5	88	-
GL	GTGL-S	MN	Ellsburg	Ellsburg_01_MW	-	33.1	Uns	Bt1	60-81	8.3	YR	3.2	2.7	31.6	88	-
GL	GTGL-S	MN	Freeon	Freeon_01_k	40A1759	41.3	No	E	21-31	9.8	YR	3.9	2.3	53.0	90	Unreg
GL	GTGL-S	MN	Freeon	Freeon_01_k	40A1759	41.3	No	Bt12	60-75	8.9	YR	4.1	3.2	36.7	90	Unreg
GL	GTGL-S	MN	Freeon	Freeon_01_k	40A1759	41.3	No	2Bt2	89-96	8.2	YR	3.9	3.1	34.2	90	Unreg
GL	GTGL-S	MN	Hibbing	Hibbing_01_k	40A1718	30.9	Uns	B1	18-23	8.6	YR	4.2	2.6	28.5	88	Unreg
GL	GTGL-S	MN	Hibbing	Hibbing_01_k	40A1718	30.9	Uns	B22	53-76	6.4	YR	3.8	3.1	33.6	88	Unreg
GL	GTGL-S	MN	Hibbing	Hibbing_01_k	40A1718	30.9	Uns	C2	122-152	7.1	YR	3.6	3.0	30.6	88	Unreg
GL	GTGL-S	MN	Mora	Mora_01_k	97P0260	22.4	Yes	E	18-41	8.2	YR	3.8	2.7	18.5	90	Unreg
GL	GTGL-S	MN	Mora	Mora_01_k	97P0260	22.4	Yes	B/E	51-66	5.9	YR	3.4	2.9	22.5	90	Unreg
GL	GTGL-S	MN	Mora	Mora_01_k	97P0260	22.4	Yes	BCd	102-165	5.6	YR	3.2	2.9	26.2	90	Unreg
GL	GTGL-S	MN	Mora	Mora_02_k	97P0263	32.3	Uns	E	15-30	9.5	YR	3.9	2.4	35.0	90	Unreg
GL	GTGL-S	MN	Mora	Mora_02_k	97P0263	32.3	Uns	2Bt1	48-74	7.8	YR	3.5	2.9	30.2	90	Unreg
GL	GTGL-S	MN	Mora	Mora_02_k	97P0263	32.3	Uns	2BC	99-132	7.7	YR	3.3	2.8	31.8	90	Unreg
GL	GTGL-S	MN	Newfound	Newfound_01_k	78P0114	39.4	Uns	B1	21-38	9.1	YR	3.7	2.9	41.9	93	Unreg
GL	GTGL-S	MN	Newfound	Newfound_01_k	78P0114	39.4	Uns	Cx1	59-94	0.1	Y	3.3	2.3	37.0	93	Unreg
GL	GTGL-S	MN	Normanna	Normanna_01_MW	-	16.2	Yes	Bw1	20-30	7.5	YR	3.1	2.4	9.2	93A	-
GL	GTGL-S	MN	Normanna	Normanna_01_MW	-	16.2	Yes	Bw2	90-100	7.5	YR	3.0	2.4	10.1	93A	-

GL	GTGL-S	MN	Normanna	Normanna_01_MW	-	16.2	Yes	2Cd	200-220	6.9	YR	2.9	2.2	29.2	93A	-
GL	GTGL-S	MN	Sanborg	Sanborg_01_MW_k	12N7626	21.4	Yes	E/B	17-25	4.2	YR	3.7	3.3	22.4	92	Unreg
GL	GTGL-S	MN	Sanborg	Sanborg_01_MW_k	12N7626	21.4	Yes	2Bk1	78-152	4.2	YR	3.8	3.2	20.3	92	Unreg
GL	GTGL-S	WI	Alban	Alban_01_k	40A1612	40.7	No	E	20-51	8.6	YR	3.5	2.8	29.9	-	Unreg
GL	GTGL-S	WI	Alban	Alban_01_k	40A1612	40.7	No	B/A	81-112	8.9	YR	3.7	3.1	46.3	-	Unreg
GL	GTGL-S	WI	Alban	Alban_01_k	40A1612	40.7	No	C1	120-143	9.1	YR	3.6	3.0	45.9	-	Unreg
GL	GTGL-S	WI	Amery	Amery_01_k	89P0252	21.1	Yes	Bs	5-25	7.8	YR	3.6	3.0	15.5	-	Unreg
GL	GTGL-S	WI	Amery	Amery_01_k	89P0252	21.1	Yes	B/E	51-74	6.5	YR	3.4	3.0	19.2	-	Unreg
GL	GTGL-S	WI	Amery	Amery_01_k	89P0252	21.1	Yes	Cd	122-152	5.7	YR	3.3	3.1	28.7	-	Unreg
GL	GTGL-S	WI	Anigon	Anigon_01_k	40A1619	45.6	No	E	25-36	9.0	YR	3.8	2.6	45.3	-	Unreg
GL	GTGL-S	WI	Anigon	Anigon_01_k	40A1619	45.6	No	Bt	51-76	8.7	YR	4.0	3.0	45.1	-	Unreg
GL	GTGL-S	WI	Anigon	Anigon_01_k	40A1619	45.6	No	2C1	86-109	8.1	YR	3.5	3.6	46.4	-	Unreg
GL	GTGL-S	WI	Anton	Anton_01_k	00P1223	20.7	Yes	E/B	10-23	6.0	YR	3.9	2.3	11.8	-	Unreg
GL	GTGL-S	WI	Anton	Anton_01_k	00P1223	20.7	Yes	Bt2	56-71	4.2	YR	3.9	3.5	23.8	-	Unreg
GL	GTGL-S	WI	Anton	Anton_01_k	00P1223	20.7	Yes	Btk2	109-124	5.9	YR	3.8	3.2	26.5	-	Unreg
GL	GTGL-S	WI	Dairyland	Dairyland_01_k	99P0297	23.5	Yes	Bw	23-56	7.2	YR	2.9	2.7	36.3	-	Unreg
GL	GTGL-S	WI	Dairyland	Dairyland_01_k	99P0297	23.5	Yes	Bt2	109-150	4.4	YR	3.5	3.3	18.2	-	Unreg
GL	GTGL-S	WI	Dairyland	Dairyland_01_k	99P0297	23.5	Yes	C	150-178	4.5	YR	3.3	3.2	16.0	-	Unreg
GL	GTGL-S	WI	Denomie	Denomie_01_k	91P0374	18.2	Yes	BE	18-33	3.7	YR	3.9	3.4	17.5	92	Unreg
GL	GTGL-S	WI	Denomie	Denomie_01_k	91P0374	18.2	Yes	Btk	71-119	3.7	YR	3.8	3.5	18.1	92	Unreg
GL	GTGL-S	WI	Denomie	Denomie_01_k	91P0374	18.2	Yes	C1	119-147	4.0	YR	3.9	3.5	18.9	92	Unreg
GL	GTGL-S	WI	Eaglebay	Eaglebay_01_k	00P1218	16.5	Yes	E	5-23	5.7	YR	3.9	2.3	8.5	-	Unreg
GL	GTGL-S	WI	Eaglebay	Eaglebay_01_k	00P1218	16.5	Yes	B/E	41-64	4.2	YR	3.9	3.3	19.7	-	Unreg
GL	GTGL-S	WI	Eaglebay	Eaglebay_01_k	00P1218	16.5	Yes	2Bt2	102-122	4.2	YR	3.9	3.5	21.3	-	Unreg
GL	GTGL-S	WI	Fence	Fence_01_k	00P1221	20.2	Yes	E	10-25	7.9	YR	3.1	1.7	25.7	92	Unreg
GL	GTGL-S	WI	Fence	Fence_01_k	00P1221	20.2	Yes	Bt1	71-102	4.9	YR	3.5	3.0	16.8	92	Unreg
GL	GTGL-S	WI	Fence	Fence_01_k	00P1221	20.2	Yes	BC	122-137	4.2	YR	3.8	3.0	18.1	92	Unreg
GL	GTGL-S	WI	Happyhollow	Happyhollow_01_k	00P1217	21.3	Yes	Bw	23-36	6.9	YR	4.3	3.3	29.0		Unreg
GL	GTGL-S	WI	Happyhollow	Happyhollow_01_k	00P1217	21.3	Yes	Bk2	51-76	4.1	YR	4.0	3.5	18.3		Unreg
GL	GTGL-S	WI	Happyhollow	Happyhollow_01_k	00P1217	21.3	Yes	2Ck1	112-137	4.3	YR	4.2	3.2	16.5		Unreg
GL	GTGL-S	WI	Haugen	Haugen_01_k	92P0440	21.4	Yes	Bw	15-41	7.0	YR	3.4	3.0	17.5	90	Unreg
GL	GTGL-S	WI	Haugen	Haugen_01_k	92P0440	21.4	Yes	B/E	66-84	5.9	YR	3.3	3.0	21.2	90	Unreg
GL	GTGL-S	WI	Haugen	Haugen_01_k	92P0440	21.4	Yes	Bt2	107-140	5.5	YR	3.3	3.2	25.6	90	Unreg
GL	GTGL-S	WI	Herbster	Herbster_01_k	00P1220	22.7	Yes	B/E	20-30	3.6	YR	3.9	3.7	23.9	-	Unreg
GL	GTGL-S	WI	Herbster	Herbster_01_k	00P1220	22.7	Yes	Btk	71-117	3.5	YR	3.8	3.7	21.5	-	Unreg
GL	GTGL-S	WI	Milaca	Milaca_01_k	04N0467	19.4	Yes	E	8-10	7.4	YR	2.9	1.6	11.3	-	Unreg
GL	GTGL-S	WI	Milaca	Milaca_01_k	04N0467	19.4	Yes	E/B	53-102	6.6	YR	3.4	3.2	19.9	-	Unreg
GL	GTGL-S	WI	Milaca	Milaca_01_k	04N0467	19.4	Yes	Cd	185-203	4.8	YR	3.3	3.2	27.1	-	Unreg
GL	GTGL-S	WI	Miskoaki	Misokoaki_01_k	91P0391	21.5	Yes	BE	5-25	4.7	YR	3.7	2.9	20.1	92	Unreg
GL	GTGL-S	WI	Miskoaki	Misokoaki_01_k	91P0391	21.5	Yes	Bt2	46-61	4.0	YR	3.6	3.5	23.1	92	Unreg

GL	GTGL-S	WI	Miskoaki	Misokoaki_01_k	91P0391	21.5	Yes	BC	102-157	4.4	YR	3.8	3.3	21.4	92	Unreg
GL	GTGL-S	WI	Newood	Newood_01_k	04N0468	16.0	Yes	E	5-8	7.2	YR	3.1	1.9	13.5	-	Unreg
GL	GTGL-S	WI	Newood	Newood_01_k	04N0468	16.0	Yes	E/B	58-91	6.5	YR	3.4	3.0	16.4	-	Unreg
GL	GTGL-S	WI	Newood	Newood_01_k	04N0468	16.0	Yes	B/E	91-130	5.6	YR	3.4	2.9	18.1	-	Unreg
GL	GTGL-S	WI	Odanah	Odanah_01_k	91P0380	21.4	Yes	BE	23-46	4.1	YR	3.8	3.3	20.7	92	Unreg
GL	GTGL-S	WI	Odanah	Odanah_01_k	91P0380	21.4	Yes	Bt2	71-91	4.3	YR	3.7	3.5	22.4	92	Unreg
GL	GTGL-S	WI	Odanah	Odanah_01_k	91P0380	21.4	Yes	C	142-193	4.4	YR	3.9	3.3	21.1	92	Unreg
GL	GTGL-S	WI	Odanah	Odanah_02_k	40A1639	19.2	Yes	A/B	13-25	5.1	YR	4.0	3.0	16.2	92	Unreg
GL	GTGL-S	WI	Odanah	Odanah_02_k	40A1639	19.2	Yes	B	58-75	4.0	YR	3.6	3.6	21.8	92	Unreg
GL	GTGL-S	WI	Odanah	Odanah_02_k	40A1639	19.2	Yes	C1	102-140	4.1	YR	4.0	3.4	19.6	92	Unreg
GL	GTGL-S	WI	Rosholt	Rosholt_01_k	89P0249	32.2	Uns	B/E	20-28	8.8	YR	3.7	2.6	31.2	90B	Unreg
GL	GTGL-S	WI	Rosholt	Rosholt_01_k	89P0249	32.2	Uns	2Bt2	51-71	7.8	YR	3.3	3.0	33.3	90B	Unreg
GL	GTGL-S	WI	Santiago	Santiago_01_k	91P0147	34.1	Uns	E/B	25-38	8.6	YR	3.8	2.8	45.9	90B	Unreg
GL	GTGL-S	WI	Santiago	Santiago_01_k	91P0147	34.1	Uns	2Bt1	58-91	6.3	YR	3.3	3.0	27.5	90B	Unreg
GL	GTGL-S	WI	Santiago	Santiago_01_k	91P0147	34.1	Uns	Cd	221-259	5.9	YR	3.7	3.5	29.1	90B	Unreg
MA	APS	MD	Frederick	Frederick_02_k	88P0498	148.8	No	Ap2	18-29	8.9	YR	3.6	2.6	222.0	147	Unreg
MA	APS	MD	Frederick	Frederick_02_k	88P0498	148.8	No	Bt2	58-81	5.1	YR	4.7	5.6	122.1	147	Unreg
MA	APS	MD	Frederick	Frederick_02_k	88P0498	148.8	No	BC	160-190	7.4	YR	4.9	5.6	102.4	147	Unreg
MA	APS	MD	Opequon	Opequon_01_k	88P0503	74.4	No	BA	20-28	8.4	YR	4.4	3.9	95.9	147	Unreg
MA	APS	MD	Opequon	Opequon_01_k	88P0503	74.4	No	Bt3	56-64	6.6	YR	4.8	5.1	68.5	147	Unreg
MA	APS	MD	Opequon	Opequon_01_k	88P0503	74.4	No	BC2	76-89	8.1	YR	4.8	4.7	59.0	147	Unreg
MA	APS	OH	Moshannon	Moshannon_03_k	00P1162	21.4	Yes	BA	8-20	6.8	YR	3.9	2.9	23.1	126	Unreg
MA	APS	OH	Moshannon	Moshannon_03_k	00P1162	21.4	Yes	Bw2	43-81	6.5	YR	3.9	3.0	20.9	126	Unreg
MA	APS	OH	Moshannon	Moshannon_03_k	00P1162	21.4	Yes	BC	109-150	6.7	YR	3.8	2.9	20.2	126	Unreg
MA	APS	OH	Nolin	Nolin_01_k	00P1155	44.7	No	Ap	0-30	9.7	YR	3.5	2.0	49.6	126	Unreg
MA	APS	OH	Nolin	Nolin_01_k	00P1155	44.7	No	Bw2	51-78	8.9	YR	3.6	2.2	51.2	126	Unreg
MA	APS	OH	Nolin	Nolin_01_k	00P1155	44.7	No	Bw4	107-140	8.4	YR	4.0	2.7	33.2	126	Unreg
MA	APS	OH	Upshur	Upshur_01_DB_k	08N0134	25.0	Yes	BA	8-24	5.4	YR	4.1	3.7	27.2	126	Unreg
MA	APS	OH	Upshur	Upshur_01_DB_k	08N0134	25.0	Yes	Bt2	40-56	5.2	YR	4.2	4.0	27.4	126	Unreg
MA	APS	OH	Upshur	Upshur_01_DB_k	08N0134	25.0	Yes	2BCss	87-101	3.8	YR	3.7	3.6	20.4	126	Unreg
MA	APS	OH	Upshur	Upshur_04_k	08N0134	25.9	Yes	BA	8-24	5.6	YR	4.1	3.7	29.5	126	Unreg
MA	APS	OH	Upshur	Upshur_04_k	08N0134	25.9	Yes	Bt3	56-72	5.2	YR	4.1	3.8	26.6	126	Unreg
MA	APS	OH	Upshur	Upshur_04_k	08N0134	25.9	Yes	2BCss	101-119	4.0	YR	3.7	3.5	21.7	126	Unreg
MA	APS	OH	Woodsfield	Woodsfield_01_DB	09OH167004	43.7	Uns	BE	23-30	9.5	YR	4.6	3.9	58.3	126	Unreg
MA	APS	OH	Woodsfield	Woodsfield_01_DB	09OH167004	43.7	Uns	2Bt3	66-81	5.3	YR	4.1	4.0	30.8	126	Unreg
MA	APS	OH	Woodsfield	Woodsfield_01_DB	09OH167004	43.7	Uns	2C	127-147	0.8	Y	5.1	3.7	42.0	126	Unreg
MA	APS	PA	Albrights	Albrights_01_CS	-	12.1	Yes	2Bt2	44-83	7.3	YR	3.9	2.3	13.3	127	-
MA	APS	PA	Albrights	Albrights_01_CS	-	12.1	Yes	2Bt3	83-135	6.1	YR	4.0	2.3	10.8	127	-
MA	APS	PA	Albrights	Albrights_02_CS	-	13.6	Yes	Bt2	43-63	7.0	YR	4.2	3.1	18.2	-	-
MA	APS	PA	Albrights	Albrights_02_CS	-	13.6	Yes	Btx	63-96	5.7	YR	3.9	2.8	13.9	-	-

MA	APS	PA	Albrights	Albrights_02_CS	-	13.6	Yes	2Ct1	96-122	5.5	YR	3.7	2.1	8.9	-	-
MA	APS	PA	Edom	Edom_01_k	13N0491	72.0	No	Ap1	0-23	9.6	YR	3.7	2.5	84.9	147	Unreg
MA	APS	PA	Edom	Edom_01_k	13N0491	72.0	No	Bt2	48-72	8.4	YR	4.9	4.5	59.1	147	Unreg
MA	APS	PA	Hustontown	Hustontown_01_k	93P0745	26.6	Yes	AB	18-30	8.4	YR	3.4	2.3	23.9	147	Unreg
MA	APS	PA	Hustontown	Hustontown_01_k	93P0745	26.6	Yes	Bt1	43-58	8.4	YR	4.6	3.7	31.8	147	Unreg
MA	APS	PA	Hustontown	Hustontown_01_k	93P0745	26.6	Yes	Btx	86-122	8.5	YR	4.2	3.3	24.1	147	Unreg
MA	APS	PA	Leck Kill	Leck Kill_01_k	99P0359	14.6	Yes	Ap2	10-20	8.5	YR	3.5	2.2	10.4	-	Unreg
MA	APS	PA	Leck Kill	Leck Kill_01_k	99P0359	14.6	Yes	Bt2	36-79	6.6	YR	4.0	2.8	18.8	-	Unreg
MA	APS	PA	Lily	Lily_01_k	01P0065	76.6	No	Bw1	23-46	9.3	YR	4.1	3.5	76.6	126	Unreg
MA	APS	PA	Morrison	Morrison_01_k	05N0354	69.9	No	A	5-27	1.5	Y	4.0	2.6	15.5	-	Unreg
MA	APS	PA	Morrison	Morrison_01_k	05N0354	69.9	No	Bt1	50-65	6.4	YR	4.6	5.3	124.4	-	Unreg
MA	APS	PA	Morrison	Morrison_02_k	05N0351	267.9	No	Ap	0-27	0.3	Y	3.7	2.8	124.1	-	Unreg
MA	APS	PA	Morrison	Morrison_02_k	05N0351	267.9	No	Bw2	48-66	9.1	YR	4.7	5.6	77.3	-	Unreg
MA	APS	PA	Morrison	Morrison_02_k	05N0351	267.9	No	Bt2	93-120	9.9	YR	4.8	4.7	602.4	-	Unreg
MA	APS	PA	Rayne	Rayne_01_k	08N0304	30.5	Uns	Bt1	10-19	8.0	YR	3.8	3.1	34.3	126	Unreg
MA	APS	PA	Rayne	Rayne_01_k	08N0304	30.5	Uns	BC	28-36	8.7	YR	4.2	3.2	26.6	126	Unreg
MA	APS	TN	Alcoa	Alcoa_01_k	95P0535	50.8	No	Ap2	10-27	6.0	YR	3.1	3.4	50.1	128	Unreg
MA	APS	TN	Alcoa	Alcoa_01_k	95P0535	50.8	No	Bt2	40-76	5.9	YR	3.7	3.9	50.0	128	Unreg
MA	APS	TN	Alcoa	Alcoa_01_k	95P0535	50.8	No	2BC	112-126	7.2	YR	4.3	4.8	52.4	128	Unreg
MA	APS	TN	Etowah	Etowah_01_k	02N0446	85.3	No	BA	13-28	7.5	YR	3.8	3.2	79.2	128	Unreg
MA	APS	TN	Etowah	Etowah_01_k	02N0446	85.3	No	Bt2	46-76	6.4	YR	4.0	3.9	87.9	128	Unreg
MA	APS	TN	Etowah	Etowah_01_k	02N0446	85.3	No	Bt4	117-163	5.7	YR	4.1	4.4	88.7	128	Unreg
MA	APS	TN	Fullerton	Fullerton_01_k	02N0448	130.7	No	E	20-30	9.5	YR	4.7	3.7	124.6	128	Unreg
MA	APS	TN	Fullerton	Fullerton_01_k	02N0448	130.7	No	Bt2	56-97	4.0	YR	4.4	5.8	131.8	128	Unreg
MA	APS	TN	Fullerton	Fullerton_01_k	02N0448	130.7	No	Bt3	97-142	3.9	YR	4.4	6.1	135.8	128	Unreg
MA	APS	TN	Neubert	Neubert_02_DM	-	18.9	Yes	Bw1	5-48	5.8	YR	3.7	3.0	28.2	128	-
MA	APS	TN	Neubert	Neubert_02_DM	-	18.9	Yes	Bw2	48-62	6.9	YR	3.4	2.7	12.3	128	-
MA	APS	TN	Neubert	Neubert_02_DM	-	18.9	Yes	C1	62-105	6.9	YR	3.2	2.7	16.2	128	-
MA	APS	TN	Neubert	Neubert_01_MO_k	95P0530	24.2	Yes	Bw	17-25	5.8	YR	3.2	2.9	28.5	128	Unreg
MA	APS	TN	Neubert	Neubert_01_MO_k	95P0530	24.2	Yes	Cb1/2	42-90	6.8	YR	3.0	3.0	25.8	128	Unreg
MA	APS	TN	Neubert	Neubert_01_MO_k	95P0530	24.2	Yes	2Bgb	245-310	9.0	YR	3.6	2.7	18.3	128	Unreg
MA	APS	TN	Neubert	Neubert_03_k	95P0531	32.6	Uns	Bw1	15-25	5.6	YR	3.3	3.0	29.7	128	Unreg
MA	APS	TN	Neubert	Neubert_03_k	95P0531	32.6	Uns	Bw3	48-74	5.8	YR	3.4	3.0	35.6	128	Unreg
MA	APS	TN	Neubert	Neubert_03_k	95P0531	32.6	Uns	Bw5	96-114	6.5	YR	3.4	2.6	32.5	128	Unreg
MA	APS	TN	Red Hills	Red Hills_01_k	95P0537	34.9	Uns	Bw1	15-33	6.1	YR	3.2	3.3	42.8	128	Unreg
MA	APS	TN	Red Hills	Red Hills_01_k	95P0537	34.9	Uns	Bw2	33-81	6.0	YR	3.8	3.9	31.8	128	Unreg
MA	APS	TN	Red Hills	Red Hills_01_k	95P0537	34.9	Uns	C	81-111	6.6	YR	3.4	3.5	30.2	128	Unreg
MA	APS	TN	Salacoa	Salacoa_01_k	01N0846	66.0	No	BA	16-36	7.7	YR	3.6	2.9	73.9	128	Reg
MA	APS	TN	Salacoa	Salacoa_01_k	01N0846	66.0	No	Bt2	59-138	7.1	YR	4.4	4.0	66.2	128	Reg
MA	APS	TN	Salacoa	Salacoa_01_k	01N0846	66.0	No	BC	168-191	8.6	YR	4.4	3.7	58.0	128	Reg

MA	APS	TN	Snd	Snd_01_k	87P0133	72.0	No	Ap	0-35	9.1	YR	3.2	1.7	108.1	128	Unreg
MA	APS	TN	Snd	Snd_01_k	87P0133	72.0	No	Bt1	50-68	9.3	YR	3.8	2.4	60.8	128	Unreg
MA	APS	TN	Snd	Snd_01_k	87P0133	72.0	No	Bt3	93-125	9.0	YR	4.1	3.1	47.2	128	Unreg
MA	APS	TN	Tellico	Tellico_01_k	95P0532	46.2	No	Bt	7-39	5.0	YR	4.1	4.4	49.6	128	Unreg
MA	APS	TN	Tellico	Tellico_01_k	95P0532	46.2	No	C/Bt1	39-68	5.0	YR	4.0	4.3	47.3	128	Unreg
MA	APS	TN	Tellico	Tellico_01_k	95P0532	46.2	No	C/Bt3	112-135	4.7	YR	4.2	4.8	41.7	128	Unreg
MA	APS	VA	Calvin	Calvin_02_JG/RA	-	10.0	Yes	A	0-10	7.7	YR	3.0	1.9	8.1	6	-
MA	APS	VA	Calvin	Calvin_02_JG/RA	-	10.0	Yes	Bt	10-75	7.8	YR	4.0	3.0	18.3	6	-
MA	APS	VA	Calvin	Calvin_02_JG/RA	-	10.0	Yes	2C	75-105	1.9	YR	3.6	2.5	3.7	6	-
MA	APS	VA	Cottonbend	Cottonbend_01_k	98P0285	115.0	No	Ap2	13-28	9.2	YR	3.5	2.7	150.8	147	Unreg
MA	APS	VA	Cottonbend	Cottonbend_01_k	98P0285	115.0	No	Bt1	51-69	7.9	YR	4.7	4.9	128.2	147	Unreg
MA	APS	VA	Cottonbend	Cottonbend_01_k	98P0285	115.0	No	2Bt3	109-137	8.1	YR	4.8	4.7	66.0	147	Unreg
MA	APS	VA	Lodi	Lodi_01_k	80P0127	97.1	No	Bt11	25-53	9.6	YR	4.6	4.3	114.1	-	Reg
MA	APS	VA	Lodi	Lodi_01_k	80P0127	97.1	No	Bt2	70-100	8.9	YR	4.6	5.1	79.6	-	Reg
MA	APS	VA	Lodi	Lodi_01_k	80P0127	97.1	No	C1	100-130	8.6	YR	4.7	5.6	97.7	-	Reg
MA	APS	WV	Albrights	Belmont_01_MR	-	11.8	Yes	BE	13-26	7.5	YR	4.3	3.1	16.7	127	-
MA	APS	WV	Albrights	Belmont_01_MR	-	11.8	Yes	Bt1	26-58	4.8	YR	3.9	2.7	11.0	127	-
MA	APS	WV	Albrights	Belmont_01_MR	-	11.8	Yes	BC	92-101	4.0	YR	3.8	2.1	7.7	127	-
MA	APS	WV	Albrights	Belmont_02_MR	-	14.6	Yes	2BC	43-61	8.2	YR	3.9	3.1	19.3	127	-
MA	APS	WV	Albrights	Belmont_02_MR	-	14.6	Yes	3C	61-75	4.9	YR	3.8	2.4	9.9	127	-
MA	APS	WV	Calvin	Calvin_01_JB	-	9.3	Yes	Ap	0-6	6.9	YR	3.7	2.4	6.4	147	-
MA	APS	WV	Calvin	Calvin_01_JB	-	9.3	Yes	Bw2	26-38	6.6	YR	4.0	2.7	12.2	147	-
MA	APS	WV	Cateache	Cateache_01_RP	-	9.7	Yes	BA	8-15	5.4	YR	3.7	2.3	9.7	127	-
MA	APS	WV	Cateache	Cateache_01_RP	-	9.7	Yes	Bt	15-56	5.6	YR	3.6	2.4	9.8	127	-
MA	APS	WV	Cateache	Cateache_02_RP	-	20.3	Yes	BA	13-23	7.5	YR	3.9	2.9	22.6	127	-
MA	APS	WV	Cateache	Cateache_02_RP	-	20.3	Yes	Bt2	41-66	6.6	YR	3.9	3.1	18.0	127	-
MA	APS	WV	Cateache	Cateache_03_JB	-	19.6	Yes	Bt1	25-51	6.3	YR	4.1	3.1	19.6	127	-
MA	APS	WV	Combs	Combs_01_RP	-	12.0	Yes	BA	15-25	8.4	YR	3.4	1.8	10.9	127	-
MA	APS	WV	Combs	Combs_01_RP	-	12.0	Yes	C1	66-114	8.0	YR	3.6	2.3	13.1	127	-
MA	APS	WV	Craigsville	Craigsville_01_JB	-	16.0	Yes	Ap	0-8	7.8	YR	2.9	2.0	6.6	127	-
MA	APS	WV	Craigsville	Craigsville_01_JB	-	16.0	Yes	Bg2	22-33	8.5	YR	3.4	2.9	25.4	127	-
MA	APS	WV	Frederick	Frederick_01_RP	-	86.3	No	Ap	0-25	9.7	YR	3.8	2.4	124.0	127	-
MA	APS	WV	Frederick	Frederick_01_RP	-	86.3	No	BA	25-38	9.4	YR	4.0	2.8	56.0	127	-
MA	APS	WV	Frederick	Frederick_01_RP	-	86.3	No	Bt2	76-127	7.3	YR	4.3	3.9	78.8	127	-
MA	APS	WV	Lehew	Lehew_01_JB	-	19.1	Yes	Bw	26-51	6.5	YR	4.3	3.7	20.7	147	-
MA	APS	WV	Lehew	Lehew_01_JB	-	19.1	Yes	CBt	51-64	5.3	YR	4.0	3.4	17.4	147	-
MA	APS	WV	Mandy	Mandy_01_SM	-	33.3	Uns	Bs	17-33	8.3	YR	4.3	3.6	29.1	126	-
MA	APS	WV	Mandy	Mandy_01_SM	-	33.3	Uns	BC	52-77	9.1	YR	4.4	3.5	37.5	126	-
MA	APS	WV	Mandy	Mandy_02_k	12N8062	56.2	No	Bs1	10-16	0.3	Y	4.4	3.6	78.6	127	Unred
MA	APS	WV	Mandy	Mandy_02_k	12N8062	56.2	No	Bw	54-76	1.7	Y	4.5	3.4	47.4	127	Unred

MA	APS	WV	Mandy	Mandy_02_k	12N8062	56.2	No	BC	76-120	1.7	Y	4.2	3.1	42.8	127	Unred
MA	APS	WV	Meckesville	Meckesville_01_k	07N0056	14.2	Yes	Bt1	25-51	6.9	YR	4.3	3.1	16.4	-	Unred
MA	APS	WV	Meckesville	Meckesville_01_k	07N0056	14.2	Yes	2Bt3	74-97	6.0	YR	3.9	2.7	12.0	-	Unred
MA	APS	WV	Melvin	Melvin_01_RP	-	177.0	No	Bw1	10-20	0.5	Y	4.9	4.0	204.7	126	-
MA	APS	WV	Melvin	Melvin_01_RP	-	177.0	No	BC	90-100	9.9	YR	4.8	4.1	149.4	126	-
MA	APS	WV	Melvin	Melvin_02_RP	-	16.2	Yes	Bw1	14-60	6.2	YR	3.7	2.8	16.5	126	-
MA	APS	WV	Melvin	Melvin_02_RP	-	16.2	Yes	Bw2	60-100	6.2	YR	3.8	2.7	15.8	126	-
MA	APS	WV	Moshannon	Moshannon_01_DB_k	03N0840	17.6	Yes	Ap	0-33	6.8	YR	3.8	2.6	17.2	126	Unreg
MA	APS	WV	Moshannon	Moshannon_01_DB_k	03N0840	17.6	Yes	Bw3	84-104	6.0	YR	3.9	3.1	17.7	126	Unreg
MA	APS	WV	Moshannon	Moshannon_01_DB_k	03N0840	17.6	Yes	C2	173-203	6.1	YR	3.9	3.0	17.9	126	Unreg
MA	APS	WV	Moshannon	Moshannon_02_DB_k	00P1162	22.8	Yes	BA	8-20	6.6	YR	3.8	3.0	21.7	126	Unreg
MA	APS	WV	Moshannon	Moshannon_02_DB_k	00P1162	22.8	Yes	Bw3	81-109	6.2	YR	3.8	3.2	21.3	126	Unreg
MA	APS	WV	Moshannon	Moshannon_02_DB_k	00P1162	22.8	Yes	C1	150-168	7.4	YR	3.9	3.3	25.5	126	Unreg
MA	APS	WV	Moshannon	Moshannon_04_k	03N0838	19.5	Yes	Bw1	20-81	6.8	YR	3.8	2.7	20.1	-	Unreg
MA	APS	WV	Moshannon	Moshannon_04_k	03N0838	19.5	Yes	C1	114-147	6.6	YR	3.8	2.6	19.0	-	Unreg
MA	APS	WV	Moshannon	Moshannon_05_k	03N0840	20.5	Yes	Ap	0-33	7.1	YR	3.8	2.5	17.9	-	Unreg
MA	APS	WV	Moshannon	Moshannon_05_k	03N0840	20.5	Yes	Bw2	48-84	6.0	YR	4.0	3.1	21.9	-	Unreg
MA	APS	WV	Moshannon	Moshannon_05_k	03N0840	20.5	Yes	BC	104-135	6.5	YR	3.7	3.0	21.6	-	Unreg
MA	APS	WV	Peabody	Peabody_01_RP	-	26.7	Yes	BA	10-20	5.8	YR	4.1	3.5	29.0	126	-
MA	APS	WV	Peabody	Peabody_01_RP	-	26.7	Yes	Bt2	60-85	3.9	YR	3.7	3.3	18.4	126	-
MA	APS	WV	Peabody	Peabody_01_RP	-	26.7	Yes	Cr	95-100	6.4	YR	4.7	3.9	32.9	126	-
MA	APS	WV	Peabody	Peabody_02_RP	-	20.4	Yes	Ap	0-10	6.9	YR	3.7	2.5	19.7	126	-
MA	APS	WV	Peabody	Peabody_02_RP	-	20.4	Yes	Bt	10-60	5.0	YR	4.1	3.3	21.2	126	-
MA	APS	WV	Peabody	Peabody_03_RP	-	20.4	Yes	BA	3-15	6.4	YR	4.1	2.8	20.9	126	-
MA	APS	WV	Peabody	Peabody_03_RP	-	20.4	Yes	Bt2	43-69	4.5	YR	3.9	3.2	19.9	126	-
MA	APS	WV	Peabody	Peabody_04_RP	-	24.7	Yes	Bt1	1-23	5.7	YR	3.7	3.2	26.3	126	-
MA	APS	WV	Peabody	Peabody_04_RP	-	24.7	Yes	BC	50-81	4.3	YR	3.7	3.3	23.1	126	-
MA	APS	WV	Pipestem	Pipestem_01_RP	-	14.3	Yes	A	0-20	8.2	YR	3.3	1.9	10.4	127	-
MA	APS	WV	Pipestem	Pipestem_01_RP	-	14.3	Yes	Bw1	28-99	8.2	YR	4.1	2.7	19.1	127	-
MA	APS	WV	Pipestem	Pipestem_01_RP	-	14.3	Yes	BC	148-200	7.1	YR	3.9	2.4	13.4	127	-
MA	APS	WV	Sensabaugh	Sensabaugh_01_RP	-	20.8	Yes	Bw1	18-65	5.5	YR	3.9	3.1	23.6	126	-
MA	APS	WV	Sensabaugh	Sensabaugh_01_RP	-	20.8	Yes	C	90-100	5.8	YR	3.6	2.9	18.0	126	-
MA	APS	WV	Upshur	Upshur_02_RP	-	32.5	Uns	BA	13-33	5.2	YR	4.1	3.5	27.9	126	-
MA	APS	WV	Upshur	Upshur_02_RP	-	32.5	Uns	Bt2	65-92	5.7	YR	4.7	4.2	37.2	126	-
MA	APS	WV	Upshur	Upshur_03_k	83P0588	37.7	Uns	BA	18-25	7.9	YR	4.1	3.3	42.6	126	Unreg
MA	APS	WV	Upshur	Upshur_03_k	83P0588	37.7	Uns	Bt21	42-57	6.6	YR	4.3	3.7	37.8	126	Unreg
MA	APS	WV	Upshur	Upshur_03_k	83P0588	37.7	Uns	BC	72-92	7.2	YR	4.3	3.7	32.8	126	Unreg
MA	APS	WV	Vandalia	Vandalia_01_RP	-	26.8	Yes	BA	13-24	6.6	YR	4.0	3.1	27.3	126	-
MA	APS	WV	Vandalia	Vandalia_01_RP	-	26.8	Yes	Bt	24-75	5.8	YR	4.2	3.3	26.3	126	-
MA	APS	WV	Vandalia	Vandalia_02_RP	-	24.2	Yes	BA	12-20	5.7	YR	3.8	3.0	19.6	126	-

MA	APS	WV	Vandalia	Vandalia_02_RP	-	24.2	Yes	2Bt2	50-100	6.6	YR	4.6	4.0	28.7	126	-
MA	GTCM	NY	Barbour	Barbour_01_k	87P0217	10.2	Yes	Bw1	20-41	5.0	YR	3.8	2.5	10.2	140	Unreg
MA	GTCM	NY	Halcott	Halcott_01_k	87P0198	41.8	No	A	0-10	9.8	YR	3.2	1.6	41.8	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_01_k	87P0219	13.5	Yes	Bw1	12-45	9.0	YR	3.9	3.2	22.9	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_01_k	87P0219	13.5	Yes	E	62-78	9.3	YR	3.6	2.2	11.9	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_01_k	87P0219	13.5	Yes	2Bx	98-116	6.6	YR	3.3	1.8	5.7	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_02_k	11N0146	12.7	Yes	Bw1	20-36	8.1	YR	3.7	2.2	12.5	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_02_k	11N0146	12.7	Yes	Bx	66-102	8.5	YR	3.6	2.1	12.8	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_03_k	87P0200	9.9	Yes	Ap	0-23	6.5	YR	3.3	2.4	8.3	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_03_k	87P0200	9.9	Yes	E	43-51	5.3	YR	3.7	2.5	10.1	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_03_k	87P0200	9.9	Yes	Bx2	107-155	5.1	YR	4.0	2.4	11.2	140	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_04_k	93P0630	11.3	Yes	BA	8-18	8.6	YR	3.2	2.1	10.7	-	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_04_k	93P0630	11.3	Yes	Bw2	44-61	8.6	YR	3.4	2.4	13.2	-	Unreg
MA	GTCM	NY	Lewbeach	Lewbeach_04_k	93P0630	11.3	Yes	Bx1	79-117	8.3	YR	3.7	2.0	10.0	-	Unreg
MA	GTCM	NY	Middlebrook	Middlebrook_01_k	93P0624	12.2	Yes	Ap	0-20	7.4	YR	3.3	2.4	9.7	-	Unreg
MA	GTCM	NY	Middlebrook	Middlebrook_01_k	93P0624	12.2	Yes	Bw	20-38	6.9	YR	3.8	3.0	15.2	-	Unreg
MA	GTCM	NY	Middlebrook	Middlebrook_01_k	93P0624	12.2	Yes	Cd	51-94	7.2	YR	3.8	2.4	11.6	-	Unreg
MA	GTCM	NY	Morris	Morris_01_k	93P0629	9.0	Yes	Bw	13-30	6.4	YR	3.7	2.6	10.4	-	Unreg
MA	GTCM	NY	Morris	Morris_01_k	93P0629	9.0	Yes	Bx	41-84	4.5	YR	3.8	2.4	8.3	-	Unreg
MA	GTCM	NY	Morris	Morris_01_k	93P0629	9.0	Yes	Cd	84-122	5.1	YR	3.6	2.3	8.2	-	Unreg
MA	GTCM	NY	Morris	Morris_04_k	92P0035	11.0	Yes	Bw	15-25	5.5	YR	3.7	2.3	9.9	-	Unreg
MA	GTCM	NY	Morris	Morris_04_k	92P0035	11.0	Yes	Bx1	41-61	6.2	YR	3.9	2.4	12.1	-	Unreg
MA	GTCM	NY	Morris	Morris_04_k	92P0035	11.0	Yes	Cd	102-168	5.8	YR	3.9	2.4	11.1	-	Unreg
MA	GTCM	NY	Onteora	Onteora_01_k	11N0147	18.3	Yes	Ap	0-28	8.6	YR	3.6	2.0	17.7	140	Unreg
MA	GTCM	NY	Onteora	Onteora_01_k	11N0147	18.3	Yes	Bw	28-51	9.5	YR	4.0	2.1	20.3	140	Unreg
MA	GTCM	NY	Onteora	Onteora_01_k	11N0147	18.3	Yes	Bx	51-157	9.6	YR	3.6	2.1	16.9	140	Unreg
MA	GTCM	NY	Onteora	Onteora_02_k	93P0625	11.1	Yes	Bw	10-33	3.6	YR	3.9	2.8	13.6	-	Unreg
MA	GTCM	NY	Onteora	Onteora_02_k	93P0625	11.1	Yes	Bx	33-112	4.2	YR	3.9	2.7	10.7	-	Unreg
MA	GTCM	NY	Onteora	Onteora_02_k	93P0625	11.1	Yes	Cd	112-183	3.7	YR	3.7	2.7	9.0	-	Unreg
MA	GTCM	NY	Vly	Vly_01_k	11N0148	11.6	Yes	Ap	0-20	7.1	YR	3.8	2.3	10.8	140	Unreg
MA	GTCM	NY	Vly	Vly_01_k	11N0148	11.6	Yes	Bw	20-51	7.5	YR	4.0	2.4	12.4	140	Unreg
MA	GTCM	NY	Vly	Vly_01_k	11N0148	11.6	Yes	BC	51-79	7.4	YR	4.0	2.3	11.8	140	Unreg
MA	GTCM	NY	Wellsboro	Wellsboro_01_OV	-	13.6	Yes	Bw	20-46	7.1	YR	3.3	2.5	13.5	140	-
MA	GTCM	NY	Wellsboro	Wellsboro_01_OV	-	13.6	Yes	Bx1	46-68	7.1	YR	3.6	2.3	10.8	140	-
MA	GTCM	NY	Wellsboro	Wellsboro_01_OV	-	13.6	Yes	C	96-120	8.2	YR	4.4	2.9	16.5	140	-
MA	GTCM	NY	Wellsboro	Wellsboro_02_k	92P0036	11.6	Yes	Bw	18-41	6.4	YR	3.5	2.3	10.3	-	Unreg
MA	GTCM	NY	Wellsboro	Wellsboro_02_k	92P0036	11.6	Yes	Bx1	56-79	7.0	YR	4.0	2.7	14.2	-	Unreg
MA	GTCM	NY	Wellsboro	Wellsboro_02_k	92P0036	11.6	Yes	Cd	132-152	6.3	YR	3.7	2.3	10.1	-	Unreg
MA	GTCM	NY	Willowemoc	Willowemoc_01_k	93P0627	10.0	Yes	Ap	0-20	4.3	YR	3.7	2.4	8.8	-	Unreg
MA	GTCM	NY	Willowemoc	Willowemoc_01_k	93P0627	10.0	Yes	Bw2	20-40	4.0	YR	4.1	2.9	11.2	-	Unreg

MA	GTCM	NY	Willowemoc	Willowemoc_02_k	11N0145	10.1	Yes	Ap	0-28	7.9	YR	3.4	2.0	7.7	140	Unreg
MA	GTCM	NY	Willowemoc	Willowemoc_02_k	11N0145	10.1	Yes	Bw2	46-53	7.2	YR	3.8	2.5	12.9	140	Unreg
MA	GTCM	NY	Willowemoc	Willowemoc_02_k	11N0145	10.1	Yes	Bx2	71-114	5.2	YR	3.8	2.2	9.7	140	Unreg
MA	GTCM	PA	Morris	Morris_02_k	93P0814	17.2	Yes	Bw1	16-38	9.3	YR	4.3	2.6	13.7	140	Unreg
MA	GTCM	PA	Morris	Morris_02_k	93P0814	17.2	Yes	Bxg	54-69	9.8	YR	4.7	3.4	23.2	140	Unreg
MA	GTCM	PA	Morris	Morris_02_k	93P0814	17.2	Yes	Bx2	92-122	7.4	YR	4.0	2.5	14.6	140	Unreg
MA	GTCM	PA	Morris	Morris_03_k	93P0815	30.5	Yes	A	8-20	8.5	YR	3.0	1.2	49.1	140	Unreg
MA	GTCM	PA	Morris	Morris_03_k	93P0815	30.5	Yes	Bx1	41-58	8.3	YR	4.0	2.6	11.9	140	Unreg
MA	NWS	AL	Gwinnett	Gwinnett_01_JS	-	71.1	No	Bt2	35-68	3.9	YR	4.3	5.6	71.1	-	-
MA	NWS	CT	Wilbraham	Wilbraham_01_DP_k	12N8263	19.5	Yes	Ap	19-32	5.4	YR	3.4	2.5	16.9	145	Unreg
MA	NWS	CT	Wilbraham	Wilbraham_01_DP_k	12N8263	19.5	Yes	Bw2	53-70	6.0	YR	3.9	3.6	20.7	145	Unreg
MA	NWS	CT	Wilbraham	Wilbraham_01_DP_k	12N8263	19.5	Yes	Cd1	70-120	6.1	YR	3.9	3.3	20.9	145	Unreg
MA	NWS	CT	Wilbraham	Wilbraham_02_DP_k	12N8265	18.5	Yes	Bw1	15-29	7.3	YR	3.7	2.6	21.4	145	Unreg
MA	NWS	CT	Wilbraham	Wilbraham_02_DP_k	12N8265	18.5	Yes	BC	46-66	6.9	YR	3.7	2.8	19.6	145	Unreg
MA	NWS	CT	Wilbraham	Wilbraham_02_DP_k	12N8265	18.5	Yes	Cd2	130-155	5.3	YR	3.3	2.4	14.6	145	Unreg
MA	NWS	MD	Christiana	Christiana_01_SM	-	52.2	No	Bt1/2	28-70	4.3	YR	4.6	5.0	52.2	-	-
MA	NWS	MD	Hagerstown	Hagerstown_01_SM	-	106.8	No	Bt1	38-50	7.1	YR	4.6	4.9	112.2	-	-
MA	NWS	MD	Hagerstown	Hagerstown_01_SM	-	106.8	No	Bt2	50-75	7.0	YR	4.6	5.0	101.3	-	-
MA	NWS	MD	Reaville	Reaville Standard	-	9.9	Yes	A/B	0-20	3.8	YR	3.6	3.2	9.9	-	-
MA	NWS	NC	Chewacla	Chewacla_01_SS	-	58.9	No	Ap1	0-7	7.8	YR	3.5	2.8	66.6	136	-
MA	NWS	NC	Chewacla	Chewacla_01_SS	-	58.9	No	Bw1	17-38	6.9	YR	3.8	3.4	51.2	136	-
MA	NWS	NC	Chewacla	Chewacla_02_SS	-	52.8	No	Ab1	12-30	6.5	YR	3.9	3.4	43.3	136	-
MA	NWS	NC	Chewacla	Chewacla_02_SS	-	52.8	No	Bw1	30-50	6.4	YR	4.1	3.8	62.4	136	-
MA	NWS	NC	Claycreek	Claycreek_01_k	87P0415	116.4	No	Bt1	20-43	1.1	Y	5.2	4.2	155.2	136	Unreg
MA	NWS	NC	Claycreek	Claycreek_01_k	87P0415	116.4	No	Bt3	81-129	0.5	Y	5.3	4.9	77.6	136	Unreg
MA	NWS	NC	Creedmoor	Creedmoor_01_k	87P0413	62.4	No	BE	16-26	0.2	Y	4.9	4.0	20.7	136	Unreg
MA	NWS	NC	Creedmoor	Creedmoor_01_k	87P0413	62.4	No	Bt2	51-80	0.2	Y	5.0	4.6	148.3	136	Unreg
MA	NWS	NC	Creedmoor	Creedmoor_01_k	87P0413	62.4	No	C	108-143	5.3	YR	3.8	2.8	18.1	136	Unreg
MA	NWS	NC	Creedmoor	Creedmoor_02_k	83P0548	31.9	Uns	E	8-20	9.6	YR	5.0	3.4	12.7	136	Unreg
MA	NWS	NC	Creedmoor	Creedmoor_02_k	83P0548	31.9	Uns	Bt1	35-61	8.4	YR	5.3	5.0	67.8	136	Unreg
MA	NWS	NC	Creedmoor	Creedmoor_02_k	83P0548	31.9	Uns	Bt3	90-150	4.1	YR	4.1	3.1	15.1	136	Unreg
MA	NWS	NC	Exway	Exway_01_k	90P0603	23.2	Yes	BC	58-81	4.0	YR	3.5	3.5	23.2	136	Unreg
MA	NWS	NC	Green Level	Green Level_01_k	00P1186	92.3	No	Bt	24-35	8.6	YR	5.0	5.0	184.4	-	Unreg
MA	NWS	NC	Green Level	Green Level_01_k	00P1186	92.3	No	Btss	54-81	7.8	YR	5.4	5.6	65.8	-	Unreg
MA	NWS	NC	Green Level	Green Level_01_k	00P1186	92.3	No	C1	92-124	8.9	YR	4.4	2.1	26.8	-	Unreg
MA	NWS	NC	Green Level	Green Level_02_k	01N0917	82.8	No	Bt	18-28	9.6	YR	5.3	4.7	112.0	-	Unreg
MA	NWS	NC	Green Level	Green Level_02_k	01N0917	82.8	No	Btss1	41-71	6.9	YR	5.2	5.1	66.1	-	Unreg
MA	NWS	NC	Green Level	Green Level_02_k	01N0917	82.8	No	BCt1	86-114	4.8	YR	4.9	5.4	70.4	-	Unreg
MA	NWS	NC	Hallison	Hallison_01_k	83P0547	59.7	No	Bt1	25-41	8.7	YR	4.5	3.4	83.8	136	Unreg
MA	NWS	NC	Hallison	Hallison_01_k	83P0547	59.7	No	Bt3	53-69	6.3	YR	4.7	4.4	35.6	136	Unreg

MA	NWS	NC	Hallison	Hallison_02_k	83P0549	59.3	No	BE	20-30	8.7	YR	4.5	3.4	83.0	136	Unreg
MA	NWS	NC	Hallison	Hallison_02_k	83P0549	59.3	No	Bt3	80-91	6.3	YR	4.4	4.7	35.6	136	Unreg
MA	NWS	NC	Mayodan	Mayodan_01_k	83P0546	49.9	No	Ap2	15-28	4.9	YR	4.1	4.3	70.4	136	Unreg
MA	NWS	NC	Mayodan	Mayodan_01_k	83P0546	49.9	No	Bt3	69-79	3.9	YR	4.0	4.5	37.2	136	Unreg
MA	NWS	NC	Mayodan	Mayodan_01_k	83P0546	49.9	No	CB	99-125	4.0	YR	4.1	4.5	42.2	136	Unreg
MA	NWS	NC	Peakin	Peakin_01_k	04N0747	19.7	Yes	Bt1	18-56	3.8	YR	3.6	3.4	22.8	-	Unreg
MA	NWS	NC	Peakin	Peakin_01_k	04N0747	19.7	Yes	BCt	135-160	4.0	YR	3.4	3.0	16.6	-	Unreg
MA	NWS	NC	Peakin	Peakin_02_k	04N0748	116.8	No	AB	18-30	7.3	YR	4.2	3.6	118.2	-	Unreg
MA	NWS	NC	Peakin	Peakin_02_k	04N0748	116.8	No	Bt2	46-86	4.1	YR	4.1	4.3	71.9	-	Unreg
MA	NWS	NC	Peakin	Peakin_02_k	04N0748	116.8	No	C	163-203	3.2	YR	4.6	5.6	160.4	-	Unreg
MA	NWS	NC	Pinkston	Pinkson_01_k	88P0666	37.1	Uns	Bt1	18-38	10.0	YR	5.2	3.8	46.6	136	Unreg
MA	NWS	NC	Pinkston	Pinkson_01_k	88P0666	37.1	Uns	BC	38-56	7.8	YR	4.7	4.0	27.6	136	Unreg
MA	NWS	NC	Polkton	Polkton_01_k	93P0068	41.4	No	Bt1	18-46	5.1	YR	4.4	5.0	67.0	136	Unreg
MA	NWS	NC	Polkton	Polkton_01_k	93P0068	41.4	No	Cr	91-132	4.7	YR	3.4	2.8	15.9	136	Unreg
MA	NWS	NJ	Abbottstown	Abbottstown_01_SM	-	13.0	Yes	Ap	0-20	7.3	YR	3.8	2.8	10.4	148	-
MA	NWS	NJ	Abbottstown	Abbottstown_01_SM	-	13.0	Yes	B	20-30	6.3	YR	4.0	3.2	15.6	148	-
MA	NWS	NJ	Abbottstown	Abbottstown_02_SM	-	13.8	Yes	Ap	0-25	6.7	YR	3.5	2.6	10.6	148	-
MA	NWS	NJ	Abbottstown	Abbottstown_02_SM	-	13.8	Yes	B	25-36	6.0	YR	3.9	3.3	17.0	148	-
MA	NWS	NJ	Birdsboro	Birdsboro_01_SM	-	12.6	Yes	A	0-28	5.0	YR	3.7	2.8	10.0	148	-
MA	NWS	NJ	Birdsboro	Birdsboro_01_SM	-	12.6	Yes	B	28-38	4.7	YR	4.1	3.5	15.1	148	-
MA	NWS	NJ	Boonton	Boonton_01_k	01N0327	22.2	Yes	BA	13-20	8.3	YR	3.8	2.9	20.8	144A	Unreg
MA	NWS	NJ	Boonton	Boonton_01_k	01N0327	22.2	Yes	Btx1	76-102	6.1	YR	3.6	3.1	22.2	144A	Unreg
MA	NWS	NJ	Boonton	Boonton_01_k	01N0327	22.2	Yes	CBt2	147-183	6.4	YR	3.1	2.9	23.7	144A	Unreg
MA	NWS	NJ	Brookfield	Brookfield_01_JT	-	12.5	Yes	3C3	64-124	4.6	YR	3.5	2.5	12.5	144A	-
MA	NWS	NJ	Penn	Penn_01_RS	-	15.8	Yes	Bt	9-36	5.6	YR	3.1	2.6	16.3	148	-
MA	NWS	NJ	Penn	Penn_01_RS	-	15.8	Yes	C	36-51	4.0	YR	3.3	3.0	15.2	148	-
MA	NWS	NJ	Rowland	Rowland_01_GJ	-	11.7	Yes	-	0-6	6.0	YR	3.6	2.4	7.4	148	-
MA	NWS	NJ	Rowland	Rowland_01_GJ	-	11.7	Yes	-	6-12	6.0	YR	4.0	3.0	13.7	148	-
MA	NWS	NJ	Rowland	Rowland_01_GJ	-	11.7	Yes	-	12-18	5.4	YR	3.9	2.9	14.1	148	-
MA	NWS	NJ	Wethersfield	Wethersfield_01_k	01N0331	10.0	Yes	BE	8-25	6.2	YR	3.6	2.9	12.4	144A	Unreg
MA	NWS	NJ	Wethersfield	Wethersfield_01_k	01N0331	10.0	Yes	Btx1	69-102	4.4	YR	3.4	2.8	9.0	144A	Unreg
MA	NWS	NJ	Wethersfield	Wethersfield_01_k	01N0331	10.0	Yes	BCtx	170-211	4.7	YR	3.2	2.8	8.7	144A	Unreg
MA	NWS	NY	Boonton	Boonton_02_k	09N0887	18.8	Yes	BA	9-19	7.5	YR	3.4	2.2	10.5	149B	Unreg
MA	NWS	NY	Boonton	Boonton_02_k	09N0887	18.8	Yes	Btx1	66-102	5.2	YR	4.1	3.7	21.2	149B	Unreg
MA	NWS	NY	Boonton	Boonton_02_k	09N0887	18.8	Yes	BC	170-185	4.8	YR	3.8	3.4	24.6	149B	Unreg
MA	NWS	PA	Bowmansville	Bowmansville_01_MR_k	01N0546	10.3	Yes	Ap2	13-25	6.7	YR	3.4	2.3	10.8	148	Unreg
MA	NWS	PA	Bowmansville	Bowmansville_01_MR_k	01N0546	10.3	Yes	Bw2	43-71	5.9	YR	3.6	2.5	9.8	148	Unreg
MA	NWS	PA	Readington	Readington_01_MR_k	01N0548	25.3	Yes	Bwg1	10-28	7.7	YR	3.7	2.2	11.9	148	Unreg
MA	NWS	PA	Readington	Readington_01_MR_k	01N0548	25.3	Yes	Bwg3	46-74	7.3	YR	3.9	2.5	14.3	148	Unreg
MA	NWS	PA	Readington	Readington_01_MR_k	01N0548	25.3	Yes	Btb	107-183	0.1	Y	4.8	4.3	49.7	148	Unreg

MA	NWS	PA	Reaville	Reaville_01_MR_k	01N0547	7.7	Yes	Ap	0-15	6.6	YR	2.9	1.6	0.0	148	Unreg
MA	NWS	PA	Reaville	Reaville_01_MR_k	01N0547	7.7	Yes	Bt2	41-58	4.6	YR	3.7	2.8	10.9	148	Unreg
MA	NWS	PA	Reaville	Reaville_01_MR_k	01N0547	7.7	Yes	Cr	58-69	4.7	YR	3.4	2.8	12.1	148	Unreg
MA	NWS	SC	Tawcaw	Tawcaw_01_SC	-	63.1	No	Bt1	3-15	7.0	YR	4.2	3.8	62.5	133A	-
MA	NWS	SC	Tawcaw	Tawcaw_01_SC	-	63.1	No	Bt2	15-33	7.3	YR	4.1	3.4	63.6	133A	-
MA	NWS	VA	Albano	Albano_01_GJ	-	29.9	Yes	B	25-30	8.1	YR	3.5	2.0	29.9	-	-
MA	NWS	VA	Arcola	Arcola_01_k	00P1077	28.7	Yes	Ap	0-20	7.5	YR	4.4	3.6	33.6	148	Unreg
MA	NWS	VA	Arcola	Arcola_01_k	00P1077	28.7	Yes	Bt1	20-45	7.4	YR	4.4	3.7	34.5	148	Unreg
MA	NWS	VA	Arcola	Arcola_01_k	00P1077	28.7	Yes	Bt2	45-75	6.0	YR	4.1	3.4	18.1	148	Unreg
MA	NWS	VA	Brentsville	Brentsville_01_k	00P1070	15.5	Yes	Bt1	20-56	3.0	YR	3.9	4.0	17.2	148	Unreg
MA	NWS	VA	Brentsville	Brentsville_01_k	00P1070	15.5	Yes	Bt2	56-87	3.3	YR	3.7	3.6	13.7	148	Unreg
MA	NWS	VA	Davidson	Davidson_01_JG	-	48.3	No	Bt1	17-29	2.8	YR	3.7	4.9	48.7	-	-
MA	NWS	VA	Davidson	Davidson_01_JG	-	48.3	No	Bt2	29-59	2.6	YR	3.7	4.9	48.0	-	-
MA	NWS	VA	Dulles	Dulles_01_GJ	-	38.8	Uns	A	0-25	8.1	YR	3.8	2.5	24.7	148	-
MA	NWS	VA	Dulles	Dulles_01_GJ	-	38.8	Uns	Bt	25-50	9.9	YR	4.6	3.7	73.4	148	-
MA	NWS	VA	Dulles	Dulles_01_GJ	-	38.8	Uns	2C2	90-107	6.2	YR	4.4	3.3	18.3	148	-
MA	NWS	VA	Goresville	Goresville_01_k	00P1103	69.2	No	Ap	0-26	5.6	YR	3.6	3.6	90.0	148	Unreg
MA	NWS	VA	Goresville	Goresville_01_k	00P1103	69.2	No	Bt1	26-64	3.9	YR	3.7	4.5	60.8	148	Unreg
MA	NWS	VA	Goresville	Goresville_01_k	00P1103	69.2	No	Bt2	64-104	4.1	YR	3.9	4.7	56.9	148	Unreg
MA	NWS	VA	Manassas	Manassas_01_k	00P1073	22.8	Yes	Bt1	20-40	4.8	YR	4.0	3.5	20.7	148	Unreg
MA	NWS	VA	Manassas	Manassas_01_k	00P1073	22.8	Yes	Bt2	40-84	4.4	YR	4.2	4.0	24.9	148	Unreg
MA	NWS	VA	Panorama	Panorama_01_k	00P1071	24.1	Yes	Bt1	20-49	4.2	YR	4.0	3.6	21.2	148	Unreg
MA	NWS	VA	Panorama	Panorama_01_k	00P1071	24.1	Yes	Bt2	49-77	4.1	YR	4.0	3.9	27.0	148	Unreg
MA	NWS	VA	Rowland	Rowland_02_GJ	-	39.0	Uns	Bw	3-28	5.4	YR	4.0	3.9	37.8	148	-
MA	NWS	VA	Rowland	Rowland_02_GJ	-	39.0	Uns	C1	28-66	5.3	YR	4.0	4.0	40.5	148	-
MA	NWS	VA	Rowland	Rowland_02_GJ	-	39.0	Uns	C2	66-107	5.7	YR	4.0	3.9	38.7	148	-
MA	NWS	VA	Warminster	Warminster_01_k	00P1089	92.0	No	Ap	0-26	5.3	YR	3.6	3.6	92.4	148	Unreg
MA	NWS	VA	Warminster	Warminster_01_k	00P1089	92.0	No	Bt1	26-92	3.2	YR	3.7	4.4	91.5	148	Unreg
MA	NYLAC	NY	Hilton	Hilton_01_k	40A0272	18.0	Yes	E1	20-25	8.6	YR	3.4	2.5	19.9	-	Unreg
MA	NYLAC	NY	Hilton	Hilton_01_k	40A0272	18.0	Yes	Bt	30-71	6.4	YR	3.9	3.1	19.9	-	Unreg
MA	NYLAC	NY	Hilton	Hilton_01_k	40A0272	18.0	Yes	C	71-109	7.9	YR	3.9	2.7	14.0	-	Unreg
MA	NYLAC	NY	Hilton	Hilton_02_k	40A0270	13.9	Yes	Ap	0-30	8.3	YR	3.2	2.1	12.1	-	Unreg
MA	NYLAC	NY	Hilton	Hilton_02_k	40A0270	13.9	Yes	Bt1	48-66	5.8	YR	3.8	2.9	17.1	-	Unreg
MA	NYLAC	NY	Hilton	Hilton_02_k	40A0270	13.9	Yes	C1	97-117	5.3	YR	3.5	2.7	12.4	-	Unreg
MA	NYLAC	NY	Lakemont	Lakemont_01_SS	-	28.7	Yes	A	0-25	0.2	Y	3.2	1.2	52.3	101	-
MA	NYLAC	NY	Lakemont	Lakemont_01_SS	-	28.7	Yes	B1	25-50	9.1	YR	4.3	2.8	16.7	101	-
MA	NYLAC	NY	Lakemont	Lakemont_01_SS	-	28.7	Yes	B2	50-75	9.3	YR	4.4	2.9	17.1	101	-
MA	NYLAC	NY	Odessa	Odessa_01_SS	-	17.7	Yes	Ap	0-10	8.9	YR	3.2	1.6	23.2	101	-
MA	NYLAC	NY	Odessa	Odessa_01_SS	-	17.7	Yes	B1	10-56	9.0	YR	4.0	2.1	14.8	101	-
MA	NYLAC	NY	Odessa	Odessa_01_SS	-	17.7	Yes	B2	56-76	9.0	YR	4.2	2.4	14.9	101	-

MA	NYLAC	NY	Odessa	Odessa_02_SS	-	18.9	Yes	A1	0-8	9.3	YR	3.1	1.3	28.3	101	-
MA	NYLAC	NY	Odessa	Odessa_02_SS	-	18.9	Yes	B1	53-85	9.2	YR	4.3	2.4	14.8	101	-
MA	NYLAC	NY	Odessa	Odessa_02_SS	-	18.9	Yes	B2	85-100	8.9	YR	4.2	2.4	13.5	101	-
MA	NYLAC	NY	Ovid	Ovid_01_AL	-	11.4	Yes	Bt1	20-36	3.9	YR	4.2	2.9	12.8	101	-
MA	NYLAC	NY	Ovid	Ovid_01_AL	-	11.4	Yes	Bt3	46-61	3.8	YR	4.4	2.6	10.0	101	-
MA	NYLAC	NY	Ovid	Ovid_02_AL	-	10.4	Yes	A	0-16	6.8	YR	2.8	1.5	8.4	101	-
MA	NYLAC	NY	Ovid	Ovid_02_AL	-	10.4	Yes	Bt1	16-43	3.5	YR	3.9	2.5	10.4	101	-
MA	NYLAC	NY	Ovid	Ovid_02_AL	-	10.4	Yes	Bt2	43-61	7.9	YR	4.2	2.4	12.5	101	-
MA	NYLAC	NY	Schoharie	Schoharie_01_k	94P0368	15.0	Yes	B/E	18-25	9.4	YR	4.3	2.5	14.8	-	Unreg
MA	NYLAC	NY	Schoharie	Schoharie_01_k	94P0368	15.0	Yes	Bt	25-71	8.2	YR	4.3	2.3	14.4	-	Unreg
MA	NYLAC	NY	Schoharie	Schoharie_01_k	94P0368	15.0	Yes	BC	71-107	7.4	YR	4.5	2.6	15.8	-	Unreg
MA	NYLAC	NY	Sodus	Sodus_01_k	40A0287	13.2	Yes	B	25-41	7.4	YR	3.6	2.9	15.7	-	Unreg
MA	NYLAC	NY	Sodus	Sodus_01_k	40A0287	13.2	Yes	B'x	51-97	5.8	YR	3.5	2.7	11.9	-	Unreg
MA	NYLAC	NY	Sodus	Sodus_01_k	40A0287	13.2	Yes	C2	119-142	6.2	YR	3.3	2.7	12.1	-	Unreg
N/A	HSG	HI	Kealia	Kealia_01_TR	-	182.0	No	AC	8-25	7.9	YR	2.6	1.6	354.2	163	-
N/A	HSG	HI	Kealia	Kealia_01_TR	-	182.0	No	C	28-89	6.3	YR	2.8	2.2	9.7	163	-
N/A	HSG	HI	Kealia	Kealia_02_TR	-	237.3	No	AB	8-23	6.7	YR	2.5	2.4	366.2	163	-
N/A	HSG	HI	Kealia	Kealia_02_TR	-	237.3	No	A/C2	43-76	8.1	YR	2.3	1.6	108.4	163	-
SC	PRBA-BC	TX	Brazoria	Brazoria_01_k	11N0445	33.4	Uns	Bss1	15-39	5.9	YR	3.4	2.8	32.6	-	Unreg
SC	PRBA-BC	TX	Brazoria	Brazoria_01_k	11N0445	33.4	Uns	Bss2	30-71	5.7	YR	3.5	2.8	34.1	-	Unreg
SC	PRBA-BC	TX	Brazoria	Brazoria_02_k	94P0173	42.6	No	A2	15-38	7.8	YR	3.5	2.0	44.5	-	Unreg
SC	PRBA-BC	TX	Brazoria	Brazoria_02_k	94P0173	42.6	No	Bss1	57-74	7.8	YR	3.6	2.2	42.1	-	Unreg
SC	PRBA-BC	TX	Brazoria	Brazoria_02_k	94P0173	42.6	No	Bss3	94-111	6.9	YR	3.6	2.6	41.2	-	Unreg
SC	PRBA-BC	TX	Brazoria	Brazoria_03_KJ	-	26.2	Yes	AB	12-21	5.8	YR	3.8	2.6	26.0	-	-
SC	PRBA-BC	TX	Brazoria	Brazoria_03_KJ	-	26.2	Yes	B2	34-55	5.8	YR	3.7	2.7	26.3	-	-
SC	PRBA-BC	TX	Brazoria	Brazoria_04_KJ	-	27.7	Yes	A	0-34	5.9	YR	3.6	2.4	26.6	-	-
SC	PRBA-BC	TX	Brazoria	Brazoria_04_KJ	-	27.7	Yes	B	34-55	5.9	YR	3.7	2.6	28.7	-	-
SC	PRBA-BC	TX	Brazoria	Brazoria_05_KJ	-	30.8	Yes	B1	24-43	5.7	YR	3.5	2.8	30.7	-	-
SC	PRBA-BC	TX	Brazoria	Brazoria_05_KJ	-	30.8	Yes	B2	43-55	5.6	YR	3.5	2.9	30.8	-	-
SC	PRBA-BC	TX	Norwood	Norwood_01_k	93P0490	44.8	No	Ap2	10-25	7.8	YR	3.6	2.4	50.0	-	Unreg
SC	PRBA-BC	TX	Norwood	Norwood_01_k	93P0490	44.8	No	Bk	46-71	7.7	YR	3.9	2.7	42.5	-	Unreg
SC	PRBA-BC	TX	Norwood	Norwood_01_k	93P0490	44.8	No	BC2	86-112	7.4	YR	4.0	2.7	41.9	-	Unreg
SC	PRBA-BC	TX	Pledger	Pledger_01_k	98P0581	33.7	Uns	A/Bk	18-33	8.9	YR	3.8	2.2	34.9	-	Unreg
SC	PRBA-BC	TX	Pledger	Pledger_01_k	98P0581	33.7	Uns	Bkss1	55-102	8.6	YR	4.2	2.8	31.5	-	Unreg
SC	PRBA-BC	TX	Pledger	Pledger_01_k	98P0581	33.7	Uns	BC1	179-185	5.2	YR	4.2	3.7	34.8	-	Unreg
SC	PRBA-BC	TX	Roetex	Roetex_01_k	40A4641	30.2	Uns	A1	13-30	5.8	YR	3.5	2.6	32.3	86A	Unreg
SC	PRBA-BC	TX	Roetex	Roetex_01_k	40A4641	30.2	Uns	B2	51-137	4.7	YR	3.8	3.4	28.1	86A	Unreg
SC	PRBA-BC	TX	Ships	Ships_01_k	40A4640	28.1	Yes	A	15-86	4.8	YR	3.7	3.4	28.5	86A	Unreg
SC	PRBA-BC	TX	Ships	Ships_01_k	40A4640	28.1	Yes	B	86-137	4.6	YR	3.9	3.6	27.7	86A	Unreg
SC	PRBA-RA	AR	Rilla	Rilla_02_k	05N0216	39.6	Uns	A	20-30	7.9	YR	3.8	3.1	38.7	118	Unreg

SC	PRBA-RA	AR	Rilla	Rilla_02_k	05N0216	39.6	Uns	Bt1	43-76	7.2	YR	4.3	3.6	36.4	118	Unreg
SC	PRBA-RA	AR	Rilla	Rilla_02_k	05N0216	39.6	Uns	Bt3	97-114	7.4	YR	4.4	3.4	43.8	118	Unreg
SC	PRBA-RA	LA	Armistead	Armistead_01_MB_k	11N0008	29.6	Yes	Bss	15-35	5.2	YR	3.6	3.1	30.3	131C	Reg
SC	PRBA-RA	LA	Armistead	Armistead_01_MB_k	11N0008	29.6	Yes	2Btb1	62-85	5.8	YR	3.8	3.3	29.2	131C	Reg
SC	PRBA-RA	LA	Armistead	Armistead_01_MB_k	11N0008	29.6	Yes	2C1	135-161	5.0	YR	4.0	4.1	29.4	131C	Reg
SC	PRBA-RA	LA	Buxin	Buxin_01_MB_k	96P0353	32.3	Yes	Bw1	6-28	5.4	YR	3.5	3.1	28.8	131C	Reg
SC	PRBA-RA	LA	Buxin	Buxin_01_MB_k	96P0353	32.3	Yes	Bss1b	83-127	8.4	YR	3.8	2.6	28.0	131C	Reg
SC	PRBA-RA	LA	Buxin	Buxin_01_MB_k	96P0353	32.3	Yes	C	199-275	5.3	YR	3.9	3.9	40.1	131C	Reg
SC	PRBA-RA	LA	Eastwood	Eastwood_01_k	87P0399	106.2	No	Bt1	18-55	8.3	YR	3.8	3.2	131.1	133B	Reg
SC	PRBA-RA	LA	Eastwood	Eastwood_01_k	87P0399	106.2	No	Bt3	90-120	5.9	YR	4.4	4.9	81.3	133B	Reg
SC	PRBA-RA	LA	Forbing	Forbing_01_k	06N0858	44.8	No	Bss1	15-40	5.4	YR	4.5	5.1	57.7	133B	Reg
SC	PRBA-RA	LA	Forbing	Forbing_01_k	06N0858	44.8	No	Bkss1	71-123	4.4	YR	4.1	4.5	32.0	133B	Reg
SC	PRBA-RA	LA	Glenwild	Glenwild_01_k	98P0531	38.7	Uns	Bt2	25-43	5.8	YR	4.0	3.5	36.5	131A	Unreg
SC	PRBA-RA	LA	Glenwild	Glenwild_01_k	98P0531	38.7	Uns	2C1	88-107	7.1	YR	4.1	3.1	37.5	131A	Unreg
SC	PRBA-RA	LA	Glenwild	Glenwild_01_k	98P0531	38.7	Uns	3B'k3	194-200	7.6	YR	3.9	2.8	42.1	131A	Unreg
SC	PRBA-RA	LA	Hebert	Hebert_01_k	85P0081	60.0	No	Bg	14-40	9.5	YR	4.4	3.3	86.0	131	Unreg
SC	PRBA-RA	LA	Hebert	Hebert_01_k	85P0081	60.0	No	Bt1	40-63	8.1	YR	4.6	3.7	51.4	131	Unreg
SC	PRBA-RA	LA	Hebert	Hebert_01_k	85P0081	60.0	No	Bt3	87-114	7.1	YR	4.3	3.5	42.7	131	Unreg
SC	PRBA-RA	LA	LeBeau	LeBeau_01_ML_k	96P0250	31.1	Yes	Bw1	10-39	6.9	YR	4.0	3.2	29.2	131C	Reg
SC	PRBA-RA	LA	LeBeau	LeBeau_01_ML_k	96P0250	31.1	Yes	Bkssy1	93-112	5.1	YR	3.9	3.7	30.4	131C	Reg
SC	PRBA-RA	LA	LeBeau	LeBeau_01_ML_k	96P0250	31.1	Yes	Bss3	214-232	5.3	YR	4.0	3.7	33.8	131C	Reg
SC	PRBA-RA	LA	Meth	Meth_02_k	06N0856	78.6	No	Bt1	18-28	3.9	YR	3.8	4.8	92.6	133B	Reg
SC	PRBA-RA	LA	Meth	Meth_02_k	06N0856	78.6	No	Bt32	94-122	3.4	YR	3.6	5.1	68.0	133B	Reg
SC	PRBA-RA	LA	Meth	Meth_02_k	06N0856	78.6	No	C	185-203	6.3	YR	3.7	4.7	75.2	133B	Reg
SC	PRBA-RA	LA	Moreland	Moreland_01_MB_k	89P0043	29.9	Yes	Ap2	14-25	5.0	YR	3.6	3.4	28.4	131A	Reg
SC	PRBA-RA	LA	Moreland	Moreland_01_MB_k	89P0043	29.9	Yes	Bw2	55-74	4.8	YR	3.6	3.6	29.0	131A	Reg
SC	PRBA-RA	LA	Moreland	Moreland_01_MB_k	89P0043	29.9	Yes	2C	381-419	6.1	YR	4.1	3.8	32.4	131A	Reg
SC	PRBA-RA	LA	Moreland	Moreland_02_MB_k	96P0352	28.0	Yes	Bss1	12-37	5.1	YR	3.4	3.2	27.7	131C	Reg
SC	PRBA-RA	LA	Moreland	Moreland_02_MB_k	96P0352	28.0	Yes	Bk2	90-100	4.5	YR	3.8	3.6	28.3	131C	Reg
SC	PRBA-RA	LA	Moreland	Moreland_03_BO	-	26.6	Yes	Bt	5-13	6.4	YR	3.7	2.7	27.2	131C	-
SC	PRBA-RA	LA	Moreland	Moreland_03_BO	-	26.6	Yes	Bt2	13-51	5.8	YR	3.7	2.8	25.9	131C	-
SC	PRBA-RA	LA	Perry	Perry_01_k	85P0751	57.0	Uns	Bwg1	13-33	0.3	Y	4.1	2.3	93.9	131	Unreg
SC	PRBA-RA	LA	Perry	Perry_01_k	85P0751	57.0	Uns	2BC	64-119	6.2	YR	3.6	2.7	37.3	131	Unreg
SC	PRBA-RA	LA	Perry	Perry_01_k	85P0751	57.0	Uns	2C2	157-213	6.1	YR	3.6	2.8	39.9	131	Unreg
SC	PRBA-RA	LA	Perry	Perry_02_k	86P0923	54.6	No	Bg1	15-52	0.2	Y	4.2	2.2	74.2	131	Unreg
SC	PRBA-RA	LA	Perry	Perry_02_k	86P0923	54.6	No	Bky	135-200	5.3	YR	4.3	3.7	35.0	131	Unreg
SC	PRBA-RA	LA	Rilla	Rilla_01_k	07N0769	43.0	No	Bt/E1	18-25	8.2	YR	4.5	3.5	44.7	131B	Unreg
SC	PRBA-RA	LA	Rilla	Rilla_01_k	07N0769	43.0	No	Bt2	70-107	6.7	YR	4.1	3.4	41.3	131B	Unreg
SC	PRBA-RA	LA	Ruston	Ruston_01_k	81P0259	88.6	No	E	13-41	8.9	YR	4.5	3.5	110.1	133B	Reg
SC	PRBA-RA	LA	Ruston	Ruston_01_k	81P0259	88.6	No	Bt2	71-81	4.9	YR	4.0	4.8	78.3	133B	Reg

SC	PRBA-RA	LA	Ruston	Ruston_01_k	81P0259	88.6	No	Bt3	94-170	4.6	YR	4.3	5.4	77.6	133B	Reg
SC	PRBA-RA	LA	Sacul	Sacul_01_k	87P0400	86.2	No	E	13-33	8.7	YR	3.9	2.7	94.1	133B	Reg
SC	PRBA-RA	LA	Sacul	Sacul_01_k	87P0400	86.2	No	C/Bt	71-102	6.2	YR	4.2	4.4	93.4	133B	Reg
SC	PRBA-RA	LA	Sacul	Sacul_01_k	87P0400	86.2	No	2C1	152-213	10.0	YR	4.3	3.1	71.2	133B	Reg
SC	PRBA-RA	LA	Severn	Severn_01_MB_k	96P0351	42.0	Uns	Ap2	9-21	5.3	YR	3.6	3.3	38.0	131C	Reg
SC	PRBA-RA	LA	Severn	Severn_01_MB_k	96P0351	42.0	Uns	C2	54-58	5.2	YR	3.7	3.5	34.4	131C	Reg
SC	PRBA-RA	LA	Severn	Severn_01_MB_k	96P0351	42.0	Uns	Btb	214-235	5.3	YR	3.6	3.8	53.5	131C	Reg
SC	PRBA-RA	LA	Sonnier	Sonnier_01_k	96P0359	37.2	Uns	Bw1	13-30	4.8	YR	3.6	3.2	24.3	131	Unreg
SC	PRBA-RA	LA	Sonnier	Sonnier_01_k	96P0359	37.2	Uns	2Btgb	72-91	8.9	YR	4.7	4.1	43.6	131	Unreg
SC	PRBA-RA	LA	Sonnier	Sonnier_01_k	96P0359	37.2	Uns	2Bt/Eb2	143-171	8.1	YR	4.4	4.1	43.8	131	Unreg
SC	PRBA-RA	LA	Spurger	Spurger_01_k	90P0996	93.5	No	Bt1	15-56	5.3	YR	4.2	4.4	88.9	133B	Reg
SC	PRBA-RA	LA	Spurger	Spurger_01_k	90P0996	93.5	No	Bt4	145-175	7.3	YR	4.6	4.5	97.1	133B	Reg
SC	PRBA-RA	LA	Spurger	Spurger_01_k	90P0996	93.5	No	BC2	206-218	6.6	YR	4.2	4.8	94.6	133B	Reg
SC	PRBA-RA	LA	Sterlington	Sterlington_01_k	07N0767	31.6	Uns	E/Bt	25-35	7.6	YR	4.0	2.9	30.3	131B	Reg
SC	PRBA-RA	LA	Sterlington	Sterlington_01_k	07N0767	31.6	Uns	Bt2/E	80-94	6.3	YR	4.1	3.6	33.0	131B	Reg
SC	PRBA-RA	MS	Bruin	Bruin_01_CA	-	45.5	No	2Bw	88-98	9.2	YR	3.7	2.4	45.5	-	-
SC	PRBA-RA	MS	Commerce	Commerce_01_CA	-	43.0	No	C3	94-135	9.2	YR	4.2	2.1	43.0	-	-
SC	PRBA-RA	MS	Commerce	Commerce_02_CA	-	43.8	No	Bw2	31-51	9.0	YR	3.6	1.9	43.8	-	-
SC	PRBA-RA	MS	Newellton	Newellton_01_CA	-	52.7	No	2Bw1	66-85	9.6	YR	3.8	2.0	52.7	-	-
SC	PRBA-RA	TX	Cuthbert	Cuthbert_01_k	11N0039	71.1	No	Bt1	16-42	4.4	YR	3.7	4.4	69.6	133B	Reg
SC	PRBA-RA	TX	Cuthbert	Cuthbert_01_k	11N0039	71.1	No	BCt	65-87	3.8	YR	3.9	4.9	72.7	133B	Reg
SC	PRBA-RA	TX	Etoile	Etoile_01_k	07N0018	70.7	No	Bt	20-62	6.8	YR	4.9	5.2	83.0	133B	Reg
SC	PRBA-RA	TX	Etoile	Etoile_01_k	07N0018	70.7	No	Btkss	81-129	1.3	Y	5.4	5.0	59.6	133B	Reg
SC	PRBA-RA	TX	Etoile	Etoile_01_k	07N0018	70.7	No	Cdk	165-203	3.5	Y	4.6	4.7	69.5	133B	Reg
SC	PRBA-RA	TX	Frierson	Frierson_01_k	12N8137	91.0	No	Bt1	40-64	4.1	YR	3.8	4.6	95.6	133B	Reg
SC	PRBA-RA	TX	Frierson	Frierson_01_k	12N8137	91.0	No	Bt3	99-173	3.0	YR	3.7	4.9	88.1	133B	Reg
SC	PRBA-RA	TX	Frierson	Frierson_01_k	12N8137	91.0	No	Bt4	173-200	3.2	YR	3.7	4.8	89.1	133B	Reg
SC	PRBA-RA	TX	Meth	Meth_01_k	98P0024	98.6	No	E	9-19	8.9	YR	3.8	3.0	132.9	133B	Unreg
SC	PRBA-RA	TX	Meth	Meth_01_k	98P0024	98.6	No	Bt3	72-105	3.9	YR	4.0	5.4	81.5	133B	Unreg
SC	PRBA-RA	TX	Meth	Meth_01_k	98P0024	98.6	No	BC	172-210	5.6	YR	4.0	5.1	81.4	133B	Unreg
SC	PRBA-RA	TX	Tenaha	Tenaha_01_k	08N0476	84.5	No	Bt1	61-89	8.6	YR	4.5	4.6	67.0	133B	Reg
SC	PRBA-RA	TX	Tenaha	Tenaha_01_k	08N0476	84.5	No	C/Bt	104-136	7.3	YR	4.7	5.3	92.5	133B	Reg
SC	PRBA-RA	TX	Tenaha	Tenaha_01_k	08N0476	84.5	No	Cd	136-203	5.4	YR	4.4	5.2	93.9	133B	Reg
SC	PRBA-RA	TX	Tuscosso	Tuscosso_01_k	07N0016	59.2	No	Bw2	27-63	8.5	YR	3.7	3.5	65.8	133B	Reg
SC	PRBA-RA	TX	Tuscosso	Tuscosso_01_k	07N0016	59.2	No	Bw4	101-162	0.6	Y	4.0	3.6	51.8	133B	Reg
SC	PRBA-RA	TX	Tuscosso	Tuscosso_01_k	07N0016	59.2	No	Bw5	162-203	0.5	Y	4.2	3.9	60.1	133B	Reg
SC	PRBB	KS	Crisfield	Crisfield_01_k	00P1387	58.4	No	A	16-30	6.9	YR	3.3	2.6	67.5	79	Unreg
SC	PRBB	KS	Crisfield	Crisfield_01_k	00P1387	58.4	No	Bw2	45-62	6.9	YR	3.0	2.4	59.0	79	Unreg
SC	PRBB	KS	Crisfield	Crisfield_01_k	00P1387	58.4	No	C2	84-122	6.8	YR	4.3	4.1	48.8	79	Unreg
SC	PRBB	KS	Kingfisher	Kingfisher_03_DB/TL	-	37.5	Uns	A2	15-33	7.2	YR	3.1	1.9	46.2	-	-

SC	PRBB	KS	Kingfisher	Kingfisher_03_DB/TL	-	37.5	Uns	Bt	44-68	5.5	YR	3.6	3.4	35.5	-	-
SC	PRBB	KS	Kingfisher	Kingfisher_03_DB/TL	-	37.5	Uns	Btk	68-100	4.5	YR	3.7	3.8	30.7	-	-
SC	PRBB	KS	Weymouth	Weymouth_02_DB/TL	-	29.4	Yes	A2	15-26	5.6	YR	3.5	2.9	28.1	-	-
SC	PRBB	KS	Weymouth	Weymouth_02_DB/TL	-	29.4	Yes	Btk2	46-82	4.8	YR	3.9	4.0	30.7	-	-
SC	PRBB	KS	Zenda	Zenda_01_DB/TL	-	24.2	Yes	A2	20-42	6.7	YR	3.2	2.3	26.8	-	-
SC	PRBB	KS	Zenda	Zenda_01_DB/TL	-	24.2	Yes	C2	61-127	4.6	YR	3.6	3.7	21.6	-	-
SC	PRBB	NM	Acuff	Acuff_01_k	90P0598	42.9	No	Ap2	10-33	6.8	YR	3.2	2.2	45.5	77D	Unreg
SC	PRBB	NM	Acuff	Acuff_01_k	90P0598	42.9	No	Btk1	48-84	6.9	YR	3.5	2.5	43.2	77D	Unreg
SC	PRBB	NM	Acuff	Acuff_01_k	90P0598	42.9	No	Btk3	112-173	6.1	YR	4.5	3.7	40.0	77D	Unreg
SC	PRBB	NM	Amarillo	Amarillo_01_k	90P0595	49.1	No	Bt1	13-30	4.5	YR	3.6	4.3	58.1	77	Unreg
SC	PRBB	NM	Amarillo	Amarillo_01_k	90P0595	49.1	No	Bt4	56-86	4.1	YR	3.7	4.4	48.0	77	Unreg
SC	PRBB	NM	Amarillo	Amarillo_01_k	90P0595	49.1	No	Btk2	97-145	6.0	YR	6.2	4.6	41.2	77	Unreg
SC	PRBB	NM	Estacado	Estacado_01_k	00P0705	36.6	Uns	Ap2	5-18	7.0	YR	3.3	2.4	39.2	77D	Unreg
SC	PRBB	NM	Estacado	Estacado_01_k	00P0705	36.6	Uns	Btk	43-61	6.5	YR	4.1	3.3	36.6	77D	Unreg
SC	PRBB	NM	Estacado	Estacado_01_k	00P0705	36.6	Uns	Bk2	81-107	6.3	YR	6.3	4.0	34.1	77D	Unreg
SC	PRBB	NM	Spantara	Spantara_01_k	90P0592	49.5	No	Bt1	25-43	6.3	YR	3.7	3.7	56.0	77	Unreg
SC	PRBB	NM	Spantara	Spantara_01_k	90P0592	49.5	No	Bt4	86-114	6.6	YR	3.9	3.5	42.9	77	Unreg
SC	PRBB	OK	Arnett	Arnett_01_k	97P0501	36.3	Uns	Bt1	18-28	4.8	YR	3.3	3.1	55.0	78C	Unreg
SC	PRBB	OK	Arnett	Arnett_01_k	97P0501	36.3	Uns	2BC	79-109	5.1	YR	3.5	3.5	26.2	78C	Unreg
SC	PRBB	OK	Arnett	Arnett_01_k	97P0501	36.3	Uns	3C2	144-213	4.4	YR	4.1	4.3	27.7	78C	Unreg
SC	PRBB	OK	Arnett	Arnett_02_k	97P0501	27.2	Yes	Bt1	18-28	4.9	YR	3.2	3.0	62.8	78C	Unreg
SC	PRBB	OK	Arnett	Arnett_02_k	97P0501	27.2	Yes	2BC	79-109	7.6	YR	3.7	3.0	8.2	78C	Unreg
SC	PRBB	OK	Arnett	Arnett_02_k	97P0501	27.2	Yes	3C2	145-213	6.1	YR	3.9	3.5	10.6	78C	Unreg
SC	PRBB	OK	Aspermont	Aspermont_02_k	97P0505	41.5	Uns	Bk1	15-58	5.4	YR	4.0	3.9	40.3	78C	Unreg
SC	PRBB	OK	Aspermont	Aspermont_02_k	97P0505	41.5	Uns	BC	109-130	5.1	YR	4.5	4.7	46.8	78C	Unreg
SC	PRBB	OK	Aspermont	Aspermont_02_k	97P0505	41.5	Uns	C2	173-231	8.2	YR	4.5	3.3	37.4	78C	Unreg
SC	PRBB	OK	Beckman	Beckman_01_k	00P1355	27.0	Yes	Bw	9-35	5.5	YR	3.8	2.8	28.1	78C	Unreg
SC	PRBB	OK	Beckman	Beckman_01_k	00P1355	27.0	Yes	Bkyz2	60-104	5.0	YR	4.1	3.3	28.2	78C	Unreg
SC	PRBB	OK	Beckman	Beckman_01_k	00P1355	27.0	Yes	Byz3	160-183	4.0	YR	3.9	3.5	24.8	78C	Unreg
SC	PRBB	OK	Bocox	Bocox_01_DK_k	99P0017	54.9	No	E1	17-35	8.3	YR	4.4	3.5	65.7	80A	Unreg
SC	PRBB	OK	Bocox	Bocox_01_DK_k	99P0017	54.9	No	Bt2	86-125	7.0	YR	4.2	4.6	55.3	80A	Unreg
SC	PRBB	OK	Bocox	Bocox_01_DK_k	99P0017	54.9	No	C1	200-240	5.3	YR	3.9	4.7	43.5	80A	Unreg
SC	PRBB	OK	Carey	Carey_01_k	94P0402	60.6	No		10-20	7.7	YR	3.0	1.5	59.5	78C	Unreg
SC	PRBB	OK	Carey	Carey_01_k	94P0402	60.6	No		40-50	7.1	YR	3.1	2.1	61.6	78C	Unreg
SC	PRBB	OK	Carnasaw	Carnasaw_01_k	93P0389	86.3	No	E	6-18	8.9	YR	3.8	2.7	107.3	119	Unreg
SC	PRBB	OK	Carnasaw	Carnasaw_01_k	93P0389	86.3	No	Btss	61-112	4.4	YR	4.4	5.1	94.3	119	Unreg
SC	PRBB	OK	Carnasaw	Carnasaw_01_k	93P0389	86.3	No	Cr	148-220	1.0	Y	4.8	3.2	57.2	119	Unreg
SC	PRBB	OK	Cordell	Cordell_01_k	12N0004	18.3	Yes	Bw	10-27	3.7	YR	3.3	3.4	19.9	78C	Reg
SC	PRBB	OK	Cordell	Cordell_01_k	12N0004	18.3	Yes	Cr	27-45	3.5	YR	3.3	3.9	16.7	78C	Reg
SC	PRBB	OK	Coyle	Coyle_01_k	91P0872	45.9	No	Bt1	25-36	5.5	YR	3.1	2.7	59.2	80A	Unreg

SC	PRBB	OK	Coyle	Coyle_01_k	91P0872	45.9	No	BCt	46-69	4.2	YR	3.4	3.9	44.1	80A	Unreg
SC	PRBB	OK	Coyle	Coyle_01_k	91P0872	45.9	No	Cr	69-94	3.3	YR	3.6	5.1	34.4	80A	Unreg
SC	PRBB	OK	Darnell	Darnell_01_k	93P0390	26.8	Yes	Bw	15-31	4.9	YR	3.5	4.3	34.0	84A	Unreg
SC	PRBB	OK	Darnell	Darnell_01_k	93P0390	26.8	Yes	Cr	31-48	3.1	YR	3.5	4.9	19.5	84A	Unreg
SC	PRBB	OK	Decobb	Decobb_01_k	96P0380	32.2	Yes	A	12-45	6.1	YR	3.1	2.2	43.8	78C	Unreg
SC	PRBB	OK	Decobb	Decobb_01_k	96P0380	32.2	Yes	Bt2	91-127	4.4	YR	3.5	3.4	25.1	78C	Unreg
SC	PRBB	OK	Decobb	Decobb_01_k	96P0380	32.2	Yes	BCk	150-159	3.2	YR	3.8	4.9	27.5	78C	Unreg
SC	PRBB	OK	Devol	Devol_01_k	89P0710	53.4	No	Ap	0-30	7.1	YR	3.4	3.1	55.1	80A	Unreg
SC	PRBB	OK	Devol	Devol_01_k	89P0710	53.4	No	Bt2	51-81	6.2	YR	3.4	3.7	56.0	80A	Unreg
SC	PRBB	OK	Devol	Devol_01_k	89P0710	53.4	No	C2	107-119	6.4	YR	3.2	3.3	49.1	80A	Unreg
SC	PRBB	OK	Dill	Dill_01_k	12N0006	27.2	Yes	Ap2	16-37	4.2	YR	3.2	4.3	29.6	-	Unreg
SC	PRBB	OK	Dill	Dill_01_k	12N0006	27.2	Yes	Bw2	67-96	2.6	YR	3.5	5.0	24.9	-	Unreg
SC	PRBB	OK	Dodson	Dodson_01_k	01N1043	51.4	No	Bt1	18-30	6.1	YR	3.2	2.4	53.5	78C	Unreg
SC	PRBB	OK	Dodson	Dodson_01_k	01N1043	51.4	No	Bt4	79-112	5.0	YR	3.5	3.4	49.3	78C	Unreg
SC	PRBB	OK	Doolin	Doolin_01_k	98P0013	13.9	No	Btn	23-56	1.2	Y	3.2	1.1	2.0	80A	Unreg
SC	PRBB	OK	Doolin	Doolin_01_k	98P0013	13.9	No	Btky	81-107	2.6	Y	3.6	1.4	2.9	80A	Unreg
SC	PRBB	OK	Doolin	Doolin_01_k	98P0013	13.9	No	2BCk	160-210	4.4	YR	4.1	4.8	36.9	80A	Unreg
SC	PRBB	OK	Duke	Duke_01_k	02N0279	25.2	Yes	Bkss	13-36	4.8	YR	3.7	3.1	23.0	78C	Unreg
SC	PRBB	OK	Duke	Duke_01_k	02N0279	25.2	Yes	Bssyz1	81-122	5.5	YR	3.8	2.9	25.6	78C	Unreg
SC	PRBB	OK	Duke	Duke_01_k	02N0279	25.2	Yes	Bssyz3	142-203	5.4	YR	3.8	2.7	27.0	78C	Unreg
SC	PRBB	OK	Eda	Eda_01_k	08N0172	65.0	No	AE	10-34	7.8	YR	3.8	3.0	59.8	78C	Unreg
SC	PRBB	OK	Eda	Eda_01_k	08N0172	65.0	No	Bt1	34-64	7.3	YR	4.0	3.5	61.2	78C	Unreg
SC	PRBB	OK	Eda	Eda_01_k	08N0172	65.0	No	C	121-148	7.0	YR	4.6	4.5	74.2	78C	Unreg
SC	PRBB	OK	Foard	Foard_01_k	98P0014	36.6	Uns	Btn	10-32	8.2	YR	3.2	1.8	41.9	78C	Unreg
SC	PRBB	OK	Foard	Foard_01_k	98P0014	36.6	Uns	Btnky3	60-90	8.1	YR	3.7	2.3	33.5	78C	Unreg
SC	PRBB	OK	Foard	Foard_01_k	98P0014	36.6	Uns	2BCk	122-169	5.1	YR	4.0	4.2	34.5	78C	Unreg
SC	PRBB	OK	Grainola	Grainola_01_AC/BN	-	38.6	Uns	A	0-8	7.5	YR	3.0	1.8	37.6	80A	-
SC	PRBB	OK	Grainola	Grainola_01_AC/BN	-	38.6	Uns	BA	8-30	6.7	YR	3.3	2.4	39.6	80A	-
SC	PRBB	OK	Grandfield	Grandfield_01_k	04N1069	57.5	No	Bt1	17-30	5.5	YR	3.4	3.2	58.3	78C	Reg
SC	PRBB	OK	Grandfield	Grandfield_01_k	04N1069	57.5	No	Bt4	91-121	5.1	YR	3.5	3.5	56.7	78C	Reg
SC	PRBB	OK	Grant	Grant_01_k	87P0443	33.0	Uns	A2	13-30	6.4	YR	2.8	2.2	41.9	80A	Unreg
SC	PRBB	OK	Grant	Grant_01_k	87P0443	33.0	Uns	Bt2	68-113	4.2	YR	3.6	4.2	30.5	80A	Unreg
SC	PRBB	OK	Grant	Grant_01_k	87P0443	33.0	Uns	Cr	150-162	2.8	YR	4.0	4.9	26.7	80A	Unreg
SC	PRBB	OK	Hardeman	Hardeman_01_k	97P0507	38.8	Uns	Bw1	15-43	5.8	YR	3.3	2.8	45.0	78C	Unreg
SC	PRBB	OK	Hardeman	Hardeman_01_k	97P0507	38.8	Uns	Bw3	79-117	5.4	YR	3.6	3.2	41.6	78C	Unreg
SC	PRBB	OK	Hardeman	Hardeman_01_k	97P0507	38.8	Uns	2BCk	304-334	2.2	YR	4.1	5.5	30.0	78C	Unreg
SC	PRBB	OK	Hardeman	Hardeman_02_k	94P0720	64.2	No	Bw1	18-46	7.2	YR	3.7	3.3	70.2	78C	Unreg
SC	PRBB	OK	Hardeman	Hardeman_02_k	94P0720	64.2	No	Bw3	70-94	7.3	YR	3.7	3.2	62.1	78C	Unreg
SC	PRBB	OK	Hardeman	Hardeman_02_k	94P0720	64.2	No	Btb1	120-137	7.2	YR	3.6	3.1	60.4	78C	Unreg
SC	PRBB	OK	Heman	Heman_02_k	93P0406	26.8	Yes	Bnz	18-41	4.7	YR	3.7	3.1	22.7	78C	Unreg

SC	PRBB	OK	Heman	Heman_02_k	93P0406	26.8	Yes	Bkss	41-71	4.5	YR	3.8	3.3	23.7	78C	Unreg
SC	PRBB	OK	Heman	Heman_02_k	93P0406	26.8	Yes	2C1	71-102	5.4	YR	3.8	4.0	33.9	78C	Unreg
SC	PRBB	OK	Hinkle	Hinkle_01_k	98P0015	32.8	Uns	Btkn1	18-41	7.1	YR	3.2	2.1	41.9	78C	Unreg
SC	PRBB	OK	Hinkle	Hinkle_01_k	98P0015	32.8	Uns	Btkn4	77-107	4.6	YR	3.7	4.1	27.7	78C	Unreg
SC	PRBB	OK	Hinkle	Hinkle_01_k	98P0015	32.8	Uns	BCk	157-200	3.2	YR	4.1	5.1	28.7	78C	Unreg
SC	PRBB	OK	Hollister	Hollister_01_k	96P0382	30.9	Uns	Bw	19-36	8.2	YR	3.6	2.0	32.9	78C	Unreg
SC	PRBB	OK	Hollister	Hollister_01_k	96P0382	30.9	Uns	Bss2	78-100	8.1	YR	3.9	2.3	30.3	78C	Unreg
SC	PRBB	OK	Hollister	Hollister_01_k	96P0382	30.9	Uns	Bw	142-182	6.1	YR	4.3	3.5	29.6	78C	Unreg
SC	PRBB	OK	Ironmound	Ironmound_01_k	93P0392	20.2	Yes	Bw	25-46	3.0	YR	3.5	4.1	18.1	80A	Unreg
SC	PRBB	OK	Ironmound	Ironmound_01_k	93P0392	20.2	Yes	Cr1	46-86	2.9	YR	3.5	4.9	22.2	80A	Unreg
SC	PRBB	OK	Kingfisher	Kingfisher_01_k	88P0457	30.2	Uns	Ap	0-49	5.6	YR	3.2	2.5	32.7	80A	Unreg
SC	PRBB	OK	Kingfisher	Kingfisher_01_k	88P0457	30.2	Uns	Bt	49-69	5.0	YR	3.4	3.2	27.6	80A	Unreg
SC	PRBB	OK	Kingfisher	Kingfisher_02_k	01N1210	31.5	Uns	Ap2	8-17	4.6	YR	3.3	3.3	34.1	80A	Unreg
SC	PRBB	OK	Kingfisher	Kingfisher_02_k	01N1210	31.5	Uns	Bt3	50-66	3.6	YR	3.7	4.3	28.4	80A	Unreg
SC	PRBB	OK	Kingfisher	Kingfisher_02_k	01N1210	31.5	Uns	Cr1	102-132	3.3	YR	3.7	4.7	31.9	80A	Unreg
SC	PRBB	OK	Kirkland	Kirkland_01_k	12N7735	83.6	No	A2	2-31	8.2	YR	2.8	1.1	92.4	80A	Unreg
SC	PRBB	OK	Kirkland	Kirkland_01_k	12N7735	83.6	No	Bt	31-72	8.7	YR	3.3	1.6	74.8	80A	Unreg
SC	PRBB	OK	Kirkland	Kirkland_02_k	12N7720	50.6	No	Ap2	2-15	7.4	YR	3.5	2.2	45.9	80A	Unreg
SC	PRBB	OK	Kirkland	Kirkland_02_k	12N7720	50.6	No	Bt	15-60	7.6	YR	3.3	2.0	55.3	80A	Unreg
SC	PRBB	OK	La Casa	La Casa_01_k	97P0503	38.5	Uns	Bt1	15-30	6.0	YR	3.4	2.9	48.9	78C	Unreg
SC	PRBB	OK	La Casa	La Casa_01_k	97P0503	38.5	Uns	Btk1	87-119	5.1	YR	4.1	3.8	33.5	78C	Unreg
SC	PRBB	OK	La Casa	La Casa_01_k	97P0503	38.5	Uns	C	205-230	5.5	YR	4.3	3.7	33.1	78C	Unreg
SC	PRBB	OK	Lawton	Lawton_01_k	01N1048	44.7	No	Bt1	24-57	7.3	YR	3.2	2.1	53.9	82B	Unreg
SC	PRBB	OK	Lawton	Lawton_01_k	01N1048	44.7	No	2Bt1	87-107	6.8	YR	3.5	3.0	44.0	82B	Unreg
SC	PRBB	OK	Lawton	Lawton_01_k	01N1048	44.7	No	2Bt5	210-232	4.3	YR	3.8	4.4	36.2	82B	Unreg
SC	PRBB	OK	Lebron	Lebron_01_k	93P0391	33.8	Uns	A	24-36	5.5	YR	3.5	2.9	31.0	80A	Unreg
SC	PRBB	OK	Lebron	Lebron_01_k	93P0391	33.8	Uns	C2	46-72	5.5	YR	3.6	3.2	36.5	80A	Unreg
SC	PRBB	OK	Lucien	Lucien_01_k	91P0908	63.6	No	BA	13-20	8.0	YR	2.8	1.8	61.5	-	Unreg
SC	PRBB	OK	Lucien	Lucien_01_k	91P0908	63.6	No	Bw	20-33	7.7	YR	3.0	2.0	65.7	-	Unreg
SC	PRBB	OK	Madge	Madge_01_k	97P0393	30.1	Uns	AB	22-46	4.8	YR	3.2	2.8	36.3	78B	Unreg
SC	PRBB	OK	Madge	Madge_01_k	97P0393	30.1	Uns	BC	72-92	3.2	YR	3.6	4.3	26.6	78B	Unreg
SC	PRBB	OK	Madge	Madge_01_k	97P0393	30.1	Uns	Cr	138-200	3.3	YR	3.6	4.5	27.5	78B	Unreg
SC	PRBB	OK	Madill	Madill_01_AC/BN	-	43.3	No	A	0-5	7.7	YR	3.5	2.4	36.6	-	-
SC	PRBB	OK	Madill	Madill_01_AC/BN	-	43.3	No	C1	5-30	7.0	YR	4.2	4.2	45.3	-	-
SC	PRBB	OK	Madill	Madill_01_AC/BN	-	43.3	No	C2	30-50	7.0	YR	3.5	2.6	47.9	-	-
SC	PRBB	OK	Masham	Masham_01_k	91P0879	27.2	Yes	Bw	9-20	2.2	YR	4.0	5.3	26.0	84A	Unreg
SC	PRBB	OK	Masham	Masham_01_k	91P0879	27.2	Yes	BC	20-33	2.0	YR	4.2	5.7	27.5	84A	Unreg
SC	PRBB	OK	Masham	Masham_01_k	91P0879	27.2	Yes	Cr	33-64	2.2	YR	4.4	5.8	28.0	84A	Unreg
SC	PRBB	OK	Minco	Minco_01_k	81P0176	47.0	No	A	0-30	5.9	YR	2.7	2.3	56.8	84A	Unreg
SC	PRBB	OK	Minco	Minco_01_k	81P0176	47.0	No	Bw2	61-122	4.5	YR	3.0	3.1	47.2	84A	Unreg

SC	PRBB	OK	Minco	Minco_01_k	81P0176	47.0	No	Ck1	122-213	4.0	YR	3.2	3.6	37.0	84A	Unreg
SC	PRBB	OK	Nobscot	Nobscot_01_k	00P1360	45.7	No	A	0-25	8.2	YR	3.7	2.6	43.3	78C	Unreg
SC	PRBB	OK	Nobscot	Nobscot_01_k	00P1360	45.7	No	Bt1	81-96	5.4	YR	3.8	4.3	48.0	78C	Unreg
SC	PRBB	OK	Norge	Norge_01_k	90P0953	57.6	No	Ap2	15-27	7.9	YR	3.0	1.7	66.9	-	Unreg
SC	PRBB	OK	Norge	Norge_01_k	90P0953	57.6	No	Bt2	59-81	6.3	YR	3.5	2.9	60.5	-	Unreg
SC	PRBB	OK	Norge	Norge_01_k	90P0953	57.6	No	2Bt4	97-124	6.8	YR	3.6	3.1	45.4	-	Unreg
SC	PRBB	OK	Oakley	Oakley_01_k	97P0506	31.6	Uns	A	18-30	6.1	YR	3.7	3.3	33.8	78C	Unreg
SC	PRBB	OK	Oakley	Oakley_01_k	97P0506	31.6	Uns	Bk2	76-109	4.0	YR	4.3	5.0	30.5	78C	Unreg
SC	PRBB	OK	Oakley	Oakley_01_k	97P0506	31.6	Uns	BC1	147-216	3.6	YR	4.1	4.9	30.7	78C	Unreg
SC	PRBB	OK	Ozark	Ozark_01_k	96P0378	17.7	Yes	Ap	0-27	7.4	YR	3.3	2.5	11.5	78C	Unreg
SC	PRBB	OK	Ozark	Ozark_01_k	96P0378	17.7	Yes	Btk1	60-98	4.0	YR	4.1	4.2	23.9	78C	Unreg
SC	PRBB	OK	Pawhuska	Pawhuska_01_k	88P0468	8.5	Yes	Bt1	23-53	8.4	YR	3.3	1.9	5.3	80A	Unreg
SC	PRBB	OK	Pawhuska	Pawhuska_01_k	88P0468	8.5	Yes	By2	96-121	4.4	YR	3.5	3.3	10.1	80A	Unreg
SC	PRBB	OK	Pawhuska	Pawhuska_01_k	88P0468	8.5	Yes	2Cr	121-260	4.2	YR	3.3	3.4	10.0	80A	Unreg
SC	PRBB	OK	Pawhuska	Pawhuska_02_k	98P0016	39.2	Uns	Bn	23-55	9.0	YR	3.5	2.1	41.5	80A	Unreg
SC	PRBB	OK	Pawhuska	Pawhuska_02_k	98P0016	39.2	Uns	Btk	81-120	9.6	YR	3.6	2.2	41.5	80A	Unreg
SC	PRBB	OK	Pawhuska	Pawhuska_02_k	98P0016	39.2	Uns	2BC	150-210	6.2	YR	4.1	4.1	34.6	80A	Unreg
SC	PRBB	OK	Piedmont	Piedmont_01_k	91P0905	29.2	Yes	BA	10-20	5.5	YR	3.0	2.4	37.8	80A	Unreg
SC	PRBB	OK	Piedmont	Piedmont_01_k	91P0905	29.2	Yes	Bt2	40-54	4.2	YR	3.3	3.4	28.3	80A	Unreg
SC	PRBB	OK	Piedmont	Piedmont_01_k	91P0905	29.2	Yes	Cr1	89-132	3.0	YR	3.5	4.8	21.6	80A	Unreg
SC	PRBB	OK	Pond Creek	Pond Creek_01_k	01N1209	64.5	No	A2	21-37	7.0	YR	3.1	2.0	68.0	80A	Unreg
SC	PRBB	OK	Pond Creek	Pond Creek_01_k	01N1209	64.5	No	Bt1	53-85	6.5	YR	3.4	2.4	62.4	80A	Unreg
SC	PRBB	OK	Pond Creek	Pond Creek_01_k	01N1209	64.5	No	Bt3	105-128	5.1	YR	3.4	3.0	63.1	80A	Unreg
SC	PRBB	OK	Port	Port_01_k	90P0949	39.4	Uns	A1	35-52	5.6	YR	3.3	2.4	42.2	80A	Unreg
SC	PRBB	OK	Port	Port_01_k	90P0949	39.4	Uns	Bw	101-123	5.7	YR	3.3	2.5	41.2	80A	Unreg
SC	PRBB	OK	Port	Port_01_k	90P0949	39.4	Uns	Bw3b	217-237	4.6	YR	3.6	3.2	34.9	80A	Unreg
SC	PRBB	OK	Port	Port_02_k	00P1354	39.9	Uns	Ap2	15-29	6.4	YR	2.8	2.3	45.0	80A	Unreg
SC	PRBB	OK	Port	Port_02_k	00P1354	39.9	Uns	BA	51-69	6.0	YR	3.2	2.7	36.7	80A	Unreg
SC	PRBB	OK	Port	Port_02_k	00P1354	39.9	Uns	Bw2	92-124	5.4	YR	3.3	2.8	38.0	80A	Unreg
SC	PRBB	OK	Port	Port_03_k	91P0875	36.3	Uns	Bt1	25-48	5.2	YR	3.2	2.4	40.0	80A	Unreg
SC	PRBB	OK	Port	Port_03_k	91P0875	36.3	Uns	Bt3	66-86	5.1	YR	3.2	2.5	38.2	80A	Unreg
SC	PRBB	OK	Port	Port_03_k	91P0875	36.3	Uns	Btkb	183-208	3.0	YR	3.8	4.9	30.8	80A	Unreg
SC	PRBB	OK	Quinlan	Quinlan_01_k	94P0719	27.1	Yes	Bk2	23-41	3.5	YR	3.6	4.5	26.5	78C	Unreg
SC	PRBB	OK	Quinlan	Quinlan_01_k	94P0719	27.1	Yes	Cr2	57-85	3.4	YR	3.6	4.9	27.7	78C	Unreg
SC	PRBB	OK	Renfrow	Renfrow_01_k	90P0946	32.9	Uns	BA	18-29	6.9	YR	3.0	2.2	41.9	-	Unreg
SC	PRBB	OK	Renfrow	Renfrow_01_k	90P0946	32.9	Uns	Btk2	83-108	3.8	YR	3.8	4.7	30.0	-	Unreg
SC	PRBB	OK	Renfrow	Renfrow_01_k	90P0946	32.9	Uns	Cr1	201-224	2.2	YR	3.7	4.8	26.9	-	Unreg
SC	PRBB	OK	Renthin	Renthin_01_k	91P0902	35.4	Uns	Bt1	25-39	5.5	YR	3.2	2.8	48.3	80A	Unreg
SC	PRBB	OK	Renthin	Renthin_01_k	91P0902	35.4	Uns	Btk1	74-107	3.0	YR	3.8	4.7	30.2	80A	Unreg
SC	PRBB	OK	Renthin	Renthin_01_k	91P0902	35.4	Uns	Cr1	140-168	2.1	YR	3.9	5.3	27.5	80A	Unreg

SC	PRBB	OK	Spur	Spur_01_k	02N0276	36.8	Uns	A	16-39	6.5	YR	3.2	2.0	43.5	78C	Unreg
SC	PRBB	OK	Spur	Spur_01_k	02N0276	36.8	Uns	Bw2	59-96	5.4	YR	3.5	3.0	39.0	78C	Unreg
SC	PRBB	OK	Spur	Spur_01_k	02N0276	36.8	Uns	BCk	166-197	4.8	YR	3.7	4.0	27.9	78C	Unreg
SC	PRBB	OK	St. Paul	St. Paul_01_k	94P0400	54.1	No		20-30	7.8	YR	3.0	1.5	59.5	78C	Unreg
SC	PRBB	OK	St. Paul	St. Paul_01_k	94P0400	54.1	No		40-50	7.2	YR	3.3	2.3	48.8	78C	Unreg
SC	PRBB	OK	St. Paul	St. Paul_02_k	93P0403	44.8	No	A	20-29	7.3	YR	3.1	1.9	64.5	78C	Unreg
SC	PRBB	OK	St. Paul	St. Paul_02_k	93P0403	44.8	No	Btk1	70-110	7.3	YR	3.6	2.7	49.9	78C	Unreg
SC	PRBB	OK	St. Paul	St. Paul_02_k	93P0403	44.8	No	2C	150-183	3.7	YR	3.7	3.4	19.9	78C	Unreg
SC	PRBB	OK	Stephenville	Stephenville_01_k	97P0397	43.5	No	Bt1	15-38	7.0	YR	3.9	4.0	54.3	84A	Unreg
SC	PRBB	OK	Stephenville	Stephenville_01_k	97P0397	43.5	No	Bt3	57-84	6.5	YR	3.7	3.6	32.6	84A	Unreg
SC	PRBB	OK	Stephenville	Stephenville_02_k	97P0396	64.7	No	E	20-40	5.2	YR	3.8	4.2	65.8	84A	Unreg
SC	PRBB	OK	Stephenville	Stephenville_02_k	97P0396	64.7	No	Bt1	40-64	4.2	YR	3.9	4.7	55.4	84A	Unreg
SC	PRBB	OK	Stephenville	Stephenville_02_k	97P0396	64.7	No	Cr	102-120	5.7	YR	4.9	5.5	72.9	84A	Unreg
SC	PRBB	OK	Tabler	Tabler_01_k	09N0981	53.4	No	A2	9-27	7.9	YR	3.0	1.3	70.0	80A	Unreg
SC	PRBB	OK	Tabler	Tabler_01_k	09N0981	53.4	No	Btss2	51-71	8.1	YR	3.5	2.2	44.6	80A	Unreg
SC	PRBB	OK	Tabler	Tabler_01_k	09N0981	53.4	No	Btk	107-124	9.1	YR	4.1	2.0	45.5	80A	Unreg
SC	PRBB	OK	Tillman	Tillman_01_k	96P0379	35.0	Uns	Bt1	15-43	6.8	YR	3.3	2.2	40.6	78C	Unreg
SC	PRBB	OK	Tillman	Tillman_01_k	96P0379	35.0	Uns	Btk1	76-107	6.7	YR	3.6	2.9	30.7	78C	Unreg
SC	PRBB	OK	Tillman	Tillman_01_k	96P0379	35.0	Uns	Bk	156-188	3.1	YR	4.5	6.0	33.5	78C	Unreg
SC	PRBB	OK	Tilvern	Tilvern_01_k	98P0554	32.7	Uns	Bk1	12-28	4.9	YR	3.7	3.6	36.7	78C	Unreg
SC	PRBB	OK	Tilvern	Tilvern_01_k	98P0554	32.7	Uns	Bssk	58-78	4.6	YR	3.9	3.7	31.3	78C	Unreg
SC	PRBB	OK	Tilvern	Tilvern_01_k	98P0554	32.7	Uns	BCky	111-130	4.6	YR	4.0	3.7	30.0	78C	Unreg
SC	PRBB	OK	Tipton	Tipton_01_k	98P0552	40.3	Uns	A	13-26	6.5	YR	3.1	2.1	49.3	78C	Unreg
SC	PRBB	OK	Tipton	Tipton_01_k	98P0552	40.3	Uns	Bt3	64-117	7.6	YR	3.5	2.3	39.7	78C	Unreg
SC	PRBB	OK	Tipton	Tipton_01_k	98P0552	40.3	Uns	BC	196-229	3.8	YR	4.0	4.6	31.8	78C	Unreg
SC	PRBB	OK	Tipton	Tipton_02_k	93P0689	56.0	No	BA	22-55	8.0	YR	3.0	1.6	62.2	78	Unreg
SC	PRBB	OK	Tipton	Tipton_02_k	93P0689	56.0	No	Btk1	55-94	7.9	YR	3.3	1.9	53.0	78	Unreg
SC	PRBB	OK	Tipton	Tipton_02_k	93P0689	56.0	No	Btk3	121-144	8.1	YR	3.5	2.3	52.9	78	Unreg
SC	PRBB	OK	Treadway	Treadway_01_k	00P1358	25.8	Yes	A2	6-33	4.7	YR	3.9	3.2	26.5	78C	Unreg
SC	PRBB	OK	Treadway	Treadway_01_k	00P1358	25.8	Yes	Bkyz2	61-94	5.1	YR	3.9	2.8	25.1	78C	Unreg
SC	PRBB	OK	Waurika	Waurika_01_k	09N0980	71.7	No	Btss1	18-53	8.8	YR	3.2	1.0	85.7	80A	Unreg
SC	PRBB	OK	Waurika	Waurika_01_k	09N0980	71.7	No	Btkss	78-111	9.3	YR	3.7	1.4	57.7	80A	Unreg
SC	PRBB	OK	Westill	Westill_01_k	97P0502	31.1	Uns	Bt1	13-39	6.2	YR	3.2	2.3	39.0	78C	Unreg
SC	PRBB	OK	Westill	Westill_01_k	97P0502	31.1	Uns	Btkss1	61-101	5.5	YR	3.6	3.0	32.7	78C	Unreg
SC	PRBB	OK	Westill	Westill_01_k	97P0502	31.1	Uns	C	140-200	3.7	YR	3.6	3.6	21.7	78C	Unreg
SC	PRBB	OK	Westola	Westola_01_k	04N1068	46.6	No	Ap	0-29	6.0	YR	3.4	2.7	36.4	78C	Reg
SC	PRBB	OK	Westola	Westola_01_k	04N1068	46.6	No	Bw2	68-105	5.5	YR	3.7	3.4	56.7	78C	Reg
SC	PRBB	OK	Westola	Westola_02_k	94P0722	39.9	Uns	A2	12-26	6.0	YR	3.1	2.7	39.5	78C	Unreg
SC	PRBB	OK	Westola	Westola_02_k	94P0722	39.9	Uns	BC2	48-64	6.0	YR	3.3	3.0	38.0	78C	Unreg
SC	PRBB	OK	Westola	Westola_02_k	94P0722	39.9	Uns	C1	108-134	5.8	YR	4.0	4.0	42.1	78C	Unreg

SC	PRBB	OK	Wetbeth	Wetbeth_01_k	89P0708	38.3	Uns	A	15-33	7.5	YR	3.2	2.0	44.3	80A	Unreg
SC	PRBB	OK	Wetbeth	Wetbeth_01_k	89P0708	38.3	Uns	Bt2	58-89	7.3	YR	3.4	2.3	38.9	80A	Unreg
SC	PRBB	OK	Wetbeth	Wetbeth_01_k	89P0708	38.3	Uns	Bt4	119-156	7.2	YR	3.7	2.8	31.6	80A	Unreg
SC	PRBB	OK	Woodward	Woodward_02_k	88P0462	34.1	Uns	A	20-60	6.9	YR	3.0	2.2	48.8	78	Unreg
SC	PRBB	OK	Woodward	Woodward_02_k	88P0462	34.1	Uns	Bw2	80-130	4.8	YR	3.7	3.6	27.5	78	Unreg
SC	PRBB	OK	Woodward	Woodward_02_k	88P0462	34.1	Uns	2Cr	130-150	4.2	YR	3.6	3.7	25.8	78	Unreg
SC	PRBB	OK	Woodward	Woodward_03_k	88P0737	52.4	No	A2	8-18	6.2	YR	3.1	2.5	54.5	78C	Unreg
SC	PRBB	OK	Woodward	Woodward_03_k	88P0737	52.4	No	Bw	18-48	5.6	YR	3.3	2.8	50.2	78C	Unreg
SC	PRBB	OK	Yomont	Yomont_01_k	93P0687	29.1	Yes	AC	17-40	4.8	YR	3.3	3.1	29.2	78	Unreg
SC	PRBB	OK	Yomont	Yomont_01_k	93P0687	29.1	Yes	C2	73-122	4.4	YR	3.4	3.3	28.9	78	Unreg
SC	PRBB	TX	Acme	Acme_01_k	00P0148	37.2	Uns	Bw1	15-30	7.5	YR	3.4	1.9	40.2	78	Unreg
SC	PRBB	TX	Acme	Acme_01_k	00P0148	37.2	Uns	By1	81-99	6.9	YR	5.0	3.5	34.2	78	Unreg
SC	PRBB	TX	Aspermont	Aspermont_01_k	98P0557	38.8	Uns	Bw	14-38	5.0	YR	3.5	3.5	48.3	-	Unreg
SC	PRBB	TX	Aspermont	Aspermont_01_k	98P0557	38.8	Uns	Bk3	84-107	4.6	YR	4.4	4.9	33.1	-	Unreg
SC	PRBB	TX	Aspermont	Aspermont_01_k	98P0557	38.8	Uns	2BCk	107-147	4.2	YR	4.2	4.8	34.9	-	Unreg
SC	PRBB	TX	Berda	Berda_01_k	00P0127	49.9	No	A2	10-28	3.4	YR	3.7	4.6	60.8	77C	Unreg
SC	PRBB	TX	Berda	Berda_01_k	00P0127	49.9	No	Bw	28-61	3.4	YR	3.7	4.5	57.4	77C	Unreg
SC	PRBB	TX	Berda	Berda_01_k	00P0127	49.9	No	2Bw1	89-127	6.6	YR	3.8	2.8	31.4	77C	Unreg
SC	PRBB	TX	Birome	Birome_01_k	85P0235	134.4	No	Bt1	20-33	5.1	YR	4.4	4.9	130.1	-	Unreg
SC	PRBB	TX	Birome	Birome_01_k	85P0235	134.4	No	BC	66-96	7.8	YR	4.9	4.3	138.8	-	Unreg
SC	PRBB	TX	Bluegrove	Bluegrove_01_k	82P0160	53.1	No	Btc1	24-42	5.3	YR	3.3	3.1	65.5	78C	Unreg
SC	PRBB	TX	Bluegrove	Bluegrove_01_k	82P0160	53.1	No	BC	61-86	8.2	YR	4.2	3.6	49.9	78C	Unreg
SC	PRBB	TX	Bluegrove	Bluegrove_01_k	82P0160	53.1	No	Cr	86-101	9.6	YR	4.4	3.3	43.8	78C	Unreg
SC	PRBB	TX	Cobb	Cobb_01_k	02N0594	26.8	Yes	Bt1	12-35	4.2	YR	3.4	3.2	37.6	78	Unreg
SC	PRBB	TX	Cobb	Cobb_01_k	02N0594	26.8	Yes	BCk	100-138	3.2	YR	3.7	4.6	20.7	78	Unreg
SC	PRBB	TX	Cobb	Cobb_01_k	02N0594	26.8	Yes	Cr	161-209	3.5	YR	3.8	4.2	22.2	78	Unreg
SC	PRBB	TX	Cottonwood	Cottonwood_01_k	00P0147	47.8	No	A	0-13	7.4	YR	3.2	1.8	47.8	78	Unreg
SC	PRBB	TX	Frankirk	Frankirk_01_k	02N0592	32.8	Uns	Bt1	12-54	6.0	YR	3.3	2.6	46.1	78	Unreg
SC	PRBB	TX	Frankirk	Frankirk_01_k	02N0592	32.8	Uns	Bt3	90-115	5.7	YR	3.6	3.3	34.6	78	Unreg
SC	PRBB	TX	Frankirk	Frankirk_01_k	02N0592	32.8	Uns	2C	139-230	4.0	YR	3.6	4.0	17.7	78	Unreg
SC	PRBB	TX	Grandfield	Grandfield_02_k	80P0279	46.4	No	A2	10-25	5.6	YR	3.0	3.1	54.7	78C	Unreg
SC	PRBB	TX	Grandfield	Grandfield_02_k	80P0279	46.4	No	Bt13	95-122	4.3	YR	3.4	4.0	57.2	78C	Unreg
SC	PRBB	TX	Grandfield	Grandfield_02_k	80P0279	46.4	No	C1	232-257	4.0	YR	3.8	4.9	27.4	78C	Unreg
SC	PRBB	TX	Grandmore	Grandmore_01_k	12N8036	46.0	No	Bt1	17-39	6.6	YR	3.5	2.6	52.0	78C	Unreg
SC	PRBB	TX	Grandmore	Grandmore_01_k	12N8036	46.0	No	2Bt1	85-125	7.7	YR	4.1	2.8	39.9	78C	Unreg
SC	PRBB	TX	Kamay	Kamay_01_k	82P0156	33.0	Uns	Bt	20-44	5.5	YR	3.4	3.2	48.3	78C	Unreg
SC	PRBB	TX	Kamay	Kamay_01_k	82P0156	33.0	Uns	Btkc3	94-139	5.1	YR	3.7	3.7	24.6	78C	Unreg
SC	PRBB	TX	Kamay	Kamay_01_k	82P0156	33.0	Uns	2C	170-182	4.8	YR	3.9	3.9	26.2	78C	Unreg
SC	PRBB	TX	Kingco	Kingco_01_k	02N0590	39.7	Uns	AB	13-38	8.2	YR	3.2	1.5	50.0	78	Unreg
SC	PRBB	TX	Kingco	Kingco_01_k	02N0590	39.7	Uns	Bkss2	99-135	7.5	YR	4.2	2.9	36.5	78	Unreg

SC	PRBB	TX	Kingco	Kingco_01_k	02N0590	39.7	Uns	BCk	196-241	5.5	YR	4.2	3.7	32.6	78	Unreg
SC	PRBB	TX	Lindy	Lindy_01_k	40A4463	71.1	No	A1	10-23	6.1	YR	3.2	2.6	82.9	78B	Unreg
SC	PRBB	TX	Lindy	Lindy_01_k	40A4463	71.1	No	Bt2	51-76	6.0	YR	3.5	3.8	65.5	78B	Unreg
SC	PRBB	TX	Lindy	Lindy_01_k	40A4463	71.1	No	2B	76-102	6.8	YR	3.9	4.1	64.8	78B	Unreg
SC	PRBB	TX	Manson	Manson_01_k	98P0384	46.2	No	Bw	15-36	7.2	YR	3.6	2.4	44.3	77E	Unreg
SC	PRBB	TX	Manson	Manson_01_k	98P0384	46.2	No	Btk3	99-117	5.8	YR	4.5	4.5	48.2	77E	Unreg
SC	PRBB	TX	Olton	Olton_01_k	81P0326	52.8	No	Bt1	18-51	6.1	YR	3.5	2.8	55.7	77C	Unreg
SC	PRBB	TX	Olton	Olton_01_k	81P0326	52.8	No	Bt3	84-114	5.0	YR	3.8	3.9	50.0	77C	Unreg
SC	PRBB	TX	Pantex	Pantex_01_k	93P0659	46.2	No	Bt1	18-51	8.2	YR	3.4	2.0	45.2	77C	Unreg
SC	PRBB	TX	Pantex	Pantex_01_k	93P0659	46.2	No	Bt3	86-124	7.1	YR	3.6	2.6	48.4	77C	Unreg
SC	PRBB	TX	Pantex	Pantex_01_k	93P0659	46.2	No	Bt5	152-180	5.9	YR	3.9	3.6	45.0	77C	Unreg
SC	PRBB	TX	Plemons	Plemons_01_k	98P0387	42.5	No	Bw	15-33	7.1	YR	3.9	2.7	42.3	77E	Unreg
SC	PRBB	TX	Plemons	Plemons_01_k	98P0387	42.5	No	Btk3	89-117	6.3	YR	4.7	3.9	38.7	77E	Unreg
SC	PRBB	TX	Plemons	Plemons_01_k	98P0387	42.5	No	Btk6	193-203	5.8	YR	4.4	4.2	46.6	77E	Unreg
SC	PRBB	TX	Pullman	Pullman_01_k	80P0343	44.4	No	Bt1	15-25	7.2	YR	3.5	2.4	46.0	77	Reg
SC	PRBB	TX	Pullman	Pullman_01_k	80P0343	44.4	No	Bt3	75-88	6.5	YR	3.7	2.9	42.8	77	Reg
SC	PRBB	TX	Pyron	Pyron_01_k	04N0176	52.1	No	Bt1	16-39	7.6	YR	3.4	2.3	56.6	78	Reg
SC	PRBB	TX	Pyron	Pyron_01_k	04N0176	52.1	No	Bk1	74-95	7.6	YR	5.6	4.0	45.8	78	Reg
SC	PRBB	TX	Pyron	Pyron_01_k	04N0176	52.1	No	Bk2	95-119	6.6	YR	5.3	4.6	54.0	78	Reg
SC	PRBB	TX	Stamford	Stamford_01_k	06N0181	20.8	Yes	Bw	13-34	4.7	YR	3.3	3.1	23.3	78	Unreg
SC	PRBB	TX	Stamford	Stamford_01_k	06N0181	20.8	Yes	Bss2	66-88	4.1	YR	3.5	3.5	20.4	78	Unreg
SC	PRBB	TX	Stamford	Stamford_01_k	06N0181	20.8	Yes	Cd1	109-137	3.7	YR	3.5	3.7	18.8	78	Unreg
SC	PRBB	TX	Tillman	Tillman_02_k	00P1362	34.7	Uns	Bt1	18-43	5.9	YR	3.3	2.5	41.3	78C	Unreg
SC	PRBB	TX	Tillman	Tillman_02_k	00P1362	34.7	Uns	Btk1	69-102	5.9	YR	3.5	3.0	33.1	78C	Unreg
SC	PRBB	TX	Tillman	Tillman_02_k	00P1362	34.7	Uns	2BCk	168-203	4.6	YR	3.9	4.1	29.7	78C	Unreg
SC	PRBB	TX	Tulia	Tulia_01_k	00P0128	41.7	No	Bk	15-43	7.1	YR	5.8	4.0	43.1	77C	Unreg
SC	PRBB	TX	Tulia	Tulia_01_k	00P0128	41.7	No	Btk2	74-117	6.9	YR	5.6	4.2	40.3	77C	Unreg
SC	PRBB	TX	Vernon	Vernon_01_DK_k	81P0470	26.2	Yes	Bk	10-25	4.5	YR	4.1	4.6	30.3	78B	Unreg
SC	PRBB	TX	Vernon	Vernon_01_DK_k	81P0470	26.2	Yes	2Cr3	125-200	4.1	YR	3.5	3.6	22.2	78B	Unreg
SC	PRBB	TX	Vernon	Vernon_02_k	80P0276	21.4	Yes	Bk1	25-45	3.2	YR	3.7	3.7	19.7	78C	Unreg
SC	PRBB	TX	Vernon	Vernon_02_k	80P0276	21.4	Yes	B1	90-115	3.0	YR	3.7	3.8	20.8	78C	Unreg
SC	PRBB	TX	Vernon	Vernon_02_k	80P0276	21.4	Yes	Cr1	135-160	2.8	YR	3.8	4.0	23.6	78C	Unreg
SC	PRBB	TX	Vernon	Vernon_03_k	79P0192	21.4	Yes	Cr1	97-118	5.1	YR	3.8	3.0	21.4	78	Unreg
SC	PRBB	TX	Vernon	Vernon_04_DK/RG	-	19.1	Yes	Bk1	18-33	2.8	YR	3.7	3.8	20.8	78C	-
SC	PRBB	TX	Vernon	Vernon_04_DK/RG	-	19.1	Yes	Bk2	33-64	3.0	YR	3.7	3.5	17.3	78C	-
SC	PRBB	TX	Weymouth	Weymouth_01_k	82P0608	22.8	Yes	C/Bk2	64-86	2.9	YR	3.6	3.8	20.5	78C	Unreg
SC	PRBB	TX	Weymouth	Weymouth_01_k	82P0608	22.8	Yes	Cr2	107-119	2.8	YR	3.7	4.4	25.2	78C	Unreg
SC	PRBB	TX	Woodward	Woodward_01_k	80P0281	32.1	Uns	Bk11	12-36	4.7	YR	3.5	3.7	37.5	78B	Unreg
SC	PRBB	TX	Woodward	Woodward_01_k	80P0281	32.1	Uns	Bk21	57-82	3.8	YR	3.6	4.4	29.2	78B	Unreg
SC	PRBB	TX	Woodward	Woodward_01_k	80P0281	32.1	Uns	Crk1	102-134	3.6	YR	3.7	4.4	29.6	78B	Unreg

APPENDIX C

Digital bedrock geologic datasets used in the creation of RPM guidance maps are available on the United States Geological Survey, Mineral Resource Program's website (*https://mrdata.usgs.gov/geology/state/*). [Accessed July, 2015].

Creation, layout, etc. of digital geologic datasets are described in USGS Open-File Report(s) for the Preliminary Integrated Geologic Map Databases for the United States:

Dicken, S. W. N. C. L., Foose, J. D. H. M. P., & Hon, J. A. M. R. (2006). *Preliminary Integrated Geologic Map Databases for the United States: Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, Rhode Island, Vermont.* U.S. Geological Survey, Open File Report No. 2006-1272 (Updated December 2007, Version 1.1). [https://pubs.usgs.gov/of/2006/1272/]

Dicken, C. L., Nicholson, S. W., Horton, J. D., Foose, M. P., & Mueller, J. A. (2005). *Preliminary integrated geologic map databases for the United States: Alabama, Florida, Georgia, Mississippi, North Carolina, and South Carolina.* U.S. Geological Survey, Open File Report No. 2005-1323 (Updated December 2007, Version 1.1). [https://pubs.usgs.gov/of/2005/1323/]

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U.S. State Digital Bedrock Geologic Maps used in preparation of RPM guidance

Maps:

- Alabama
- Arkansas
- Arizona
- Colorado
- Connecticut
- Kansas
- Kentucky
- Louisiana
- Massachusetts
- Maryland
- Michigan
- Minnesota
- North Carolina
- New Jersey
- New Mexico
- New York
- Ohio
- Oklahoma
- Pennsylvanian
- Rhode Island
- South Dakota
- Tennessee
- Texas
- Utah
- Virginia
- Wisconsin
- West Virginia
- Wyoming

See individual U.S. state webpages (*https://mrdata.usgs.gov/geology/state/*) and associated Open File Report(s) for sources and descriptions of geologic units identified as problematic RPM in RPM guidance maps in the USGS Mineral Resources Program's, Integrated Geologic Map Database for the United States.

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APPENDIX D

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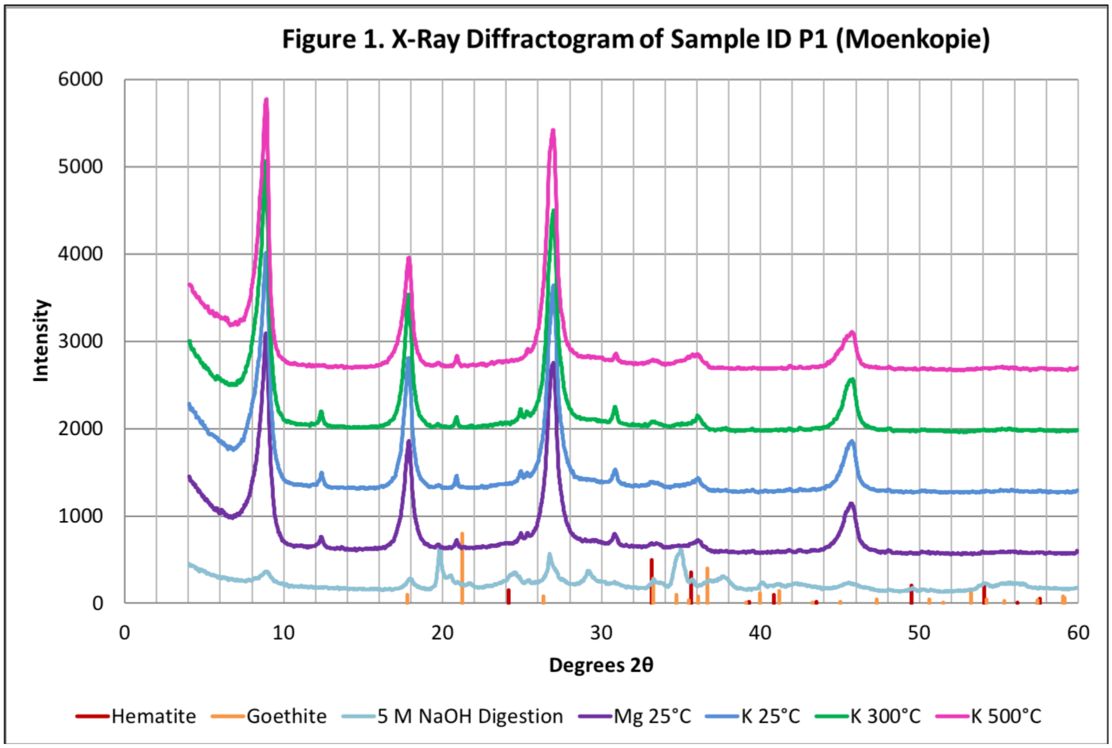
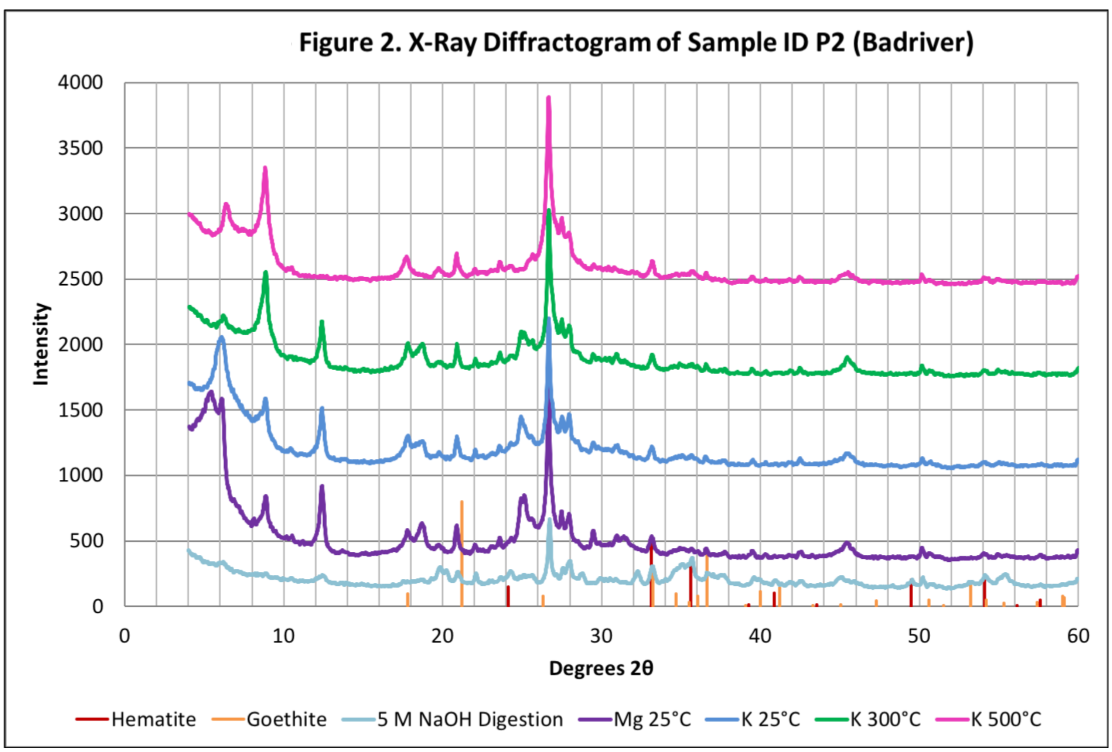
APPENDIX E

X-Ray diffractograms of problematic soil samples.





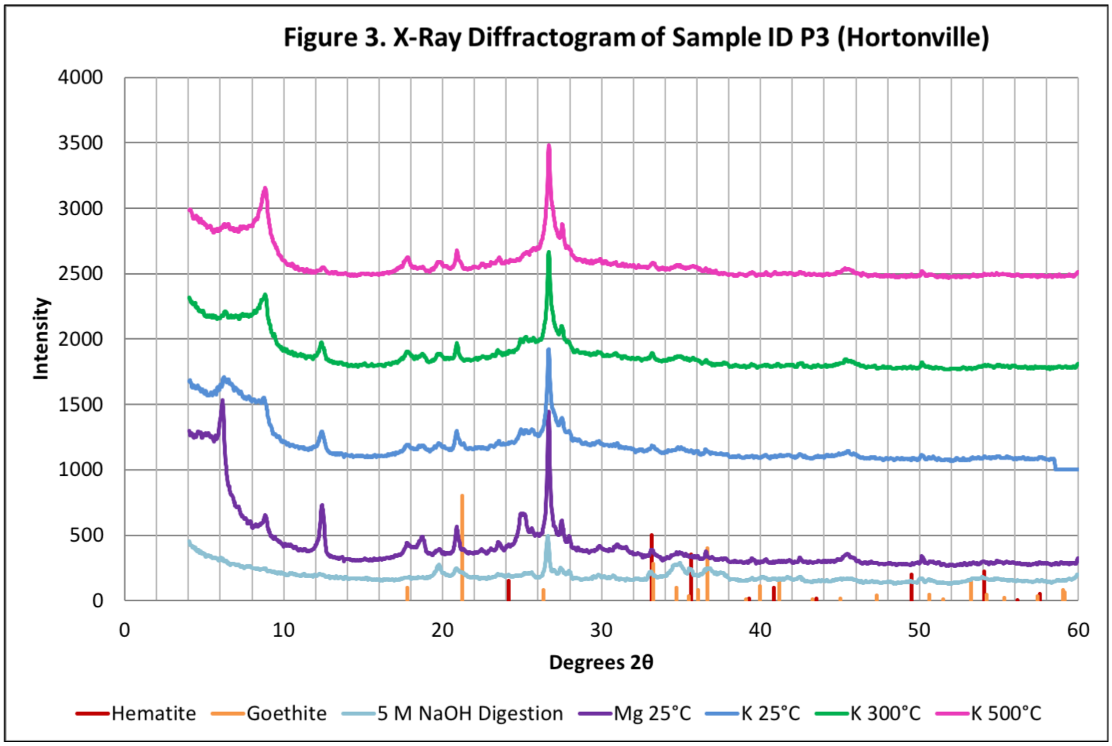


Figure 3. X-Ray Diffractogram of Sample ID P3 (Hortonville)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

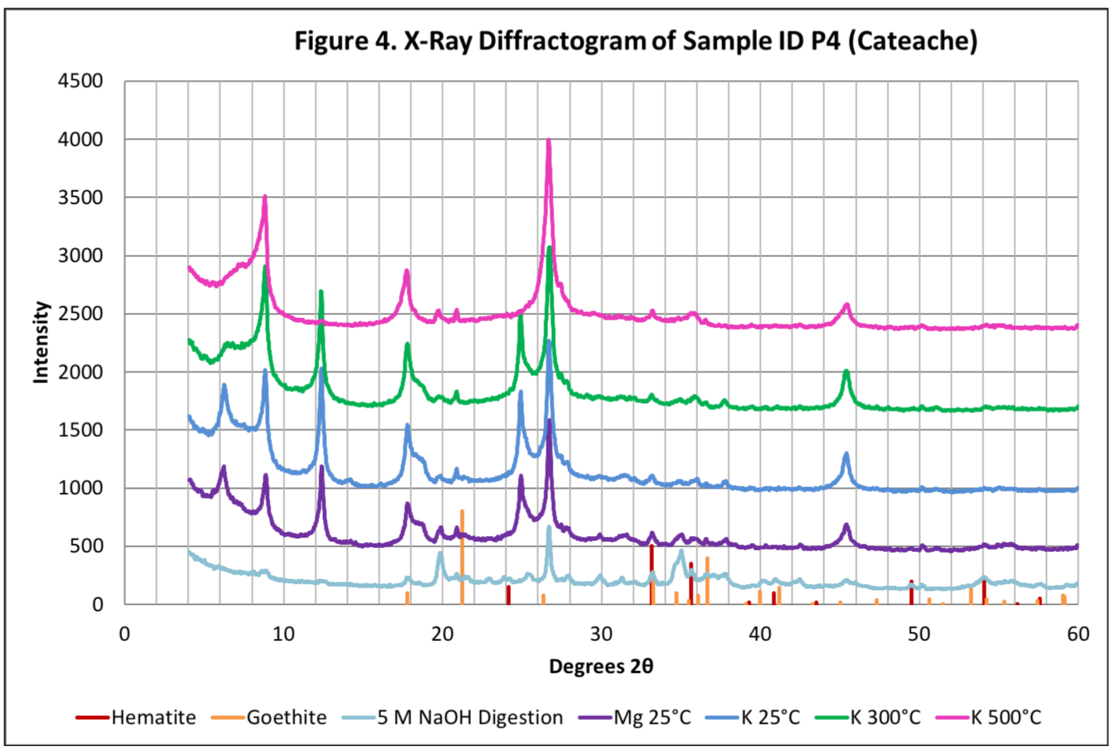


Figure 4. X-Ray Diffractogram of Sample ID P4 (Cateache)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

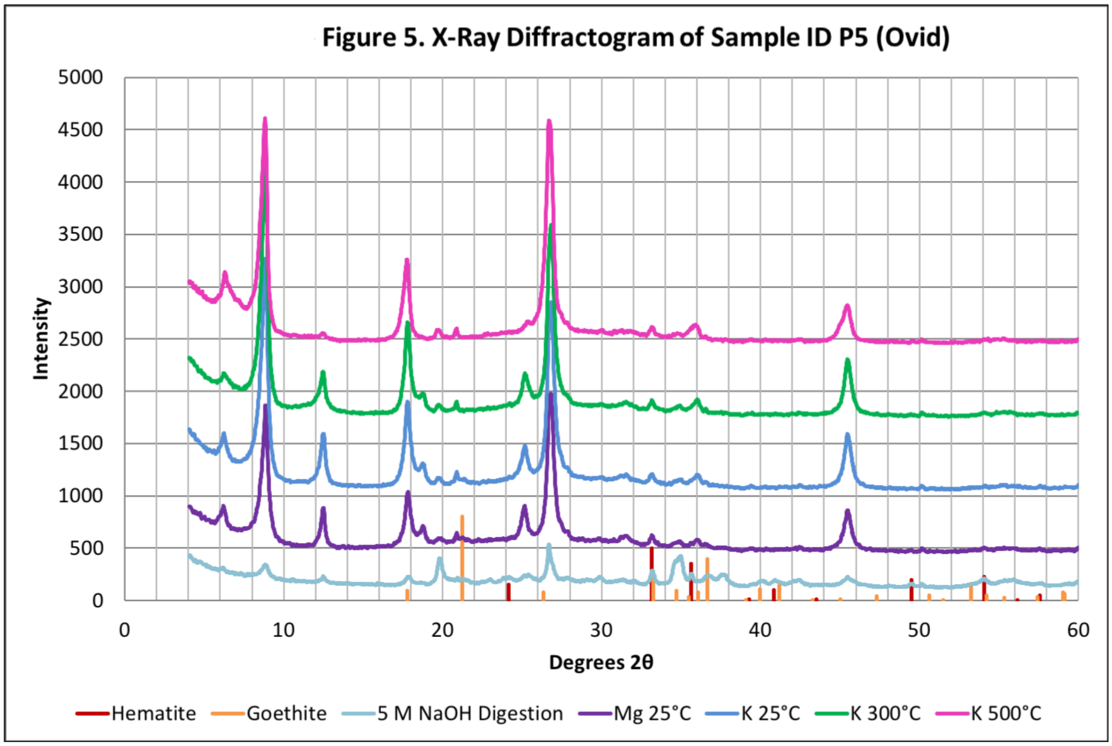


Figure 5. X-Ray Diffractogram of Sample ID P5 (Ovid)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

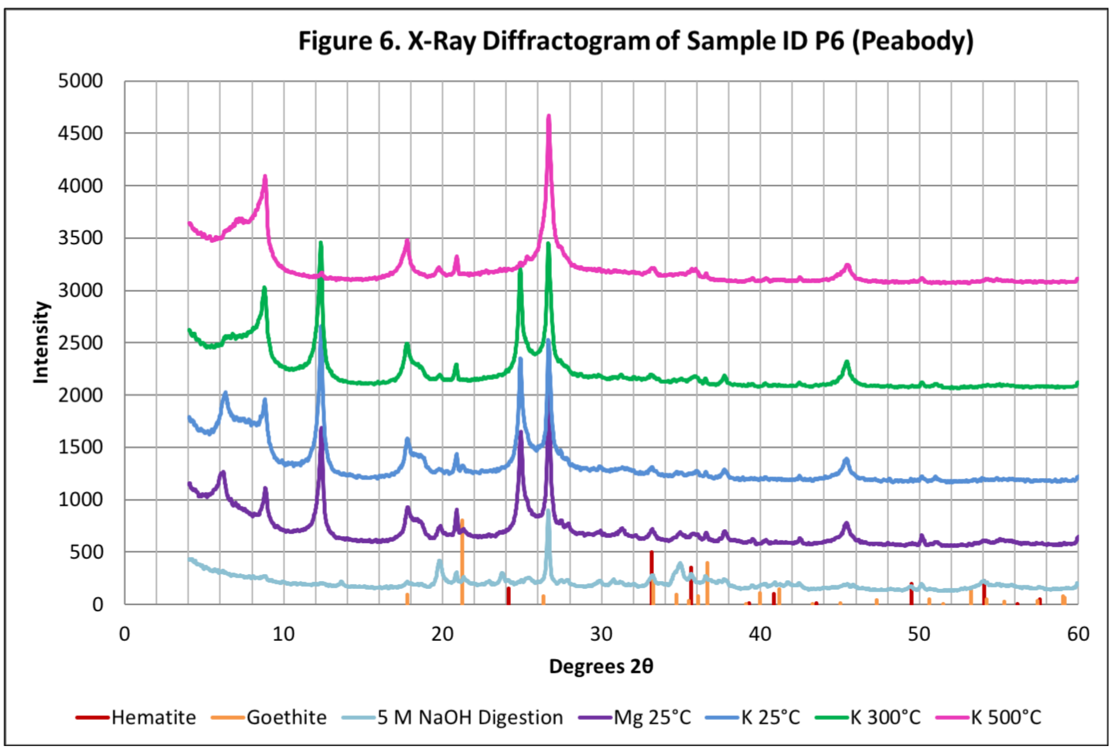


Figure 6. X-Ray Diffractogram of Sample ID P6 (Peabody)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

Figure 7. X-Ray Diffractogram of Sample ID P7 (Reaville)

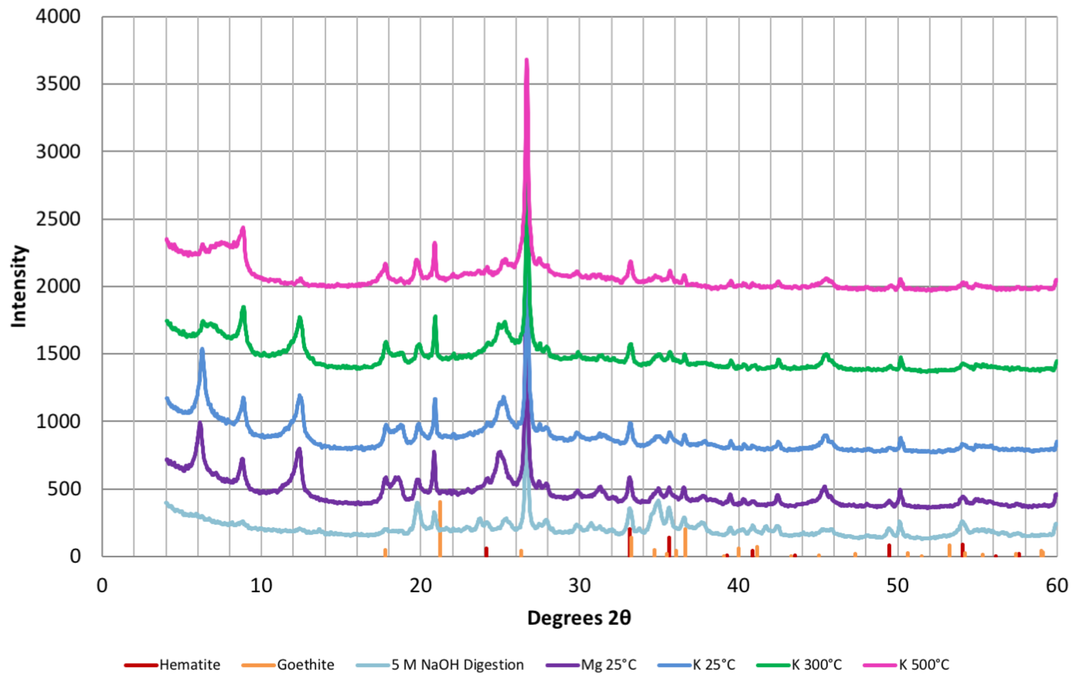
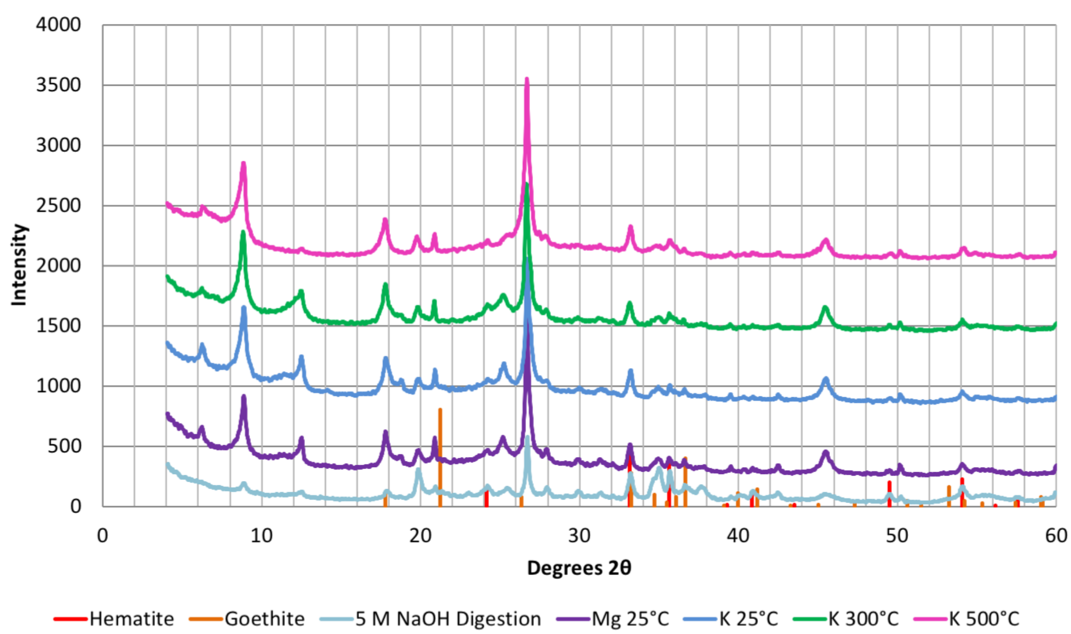


Figure 8. X-Ray Diffractogram of Sample ID P8 (Wethersfield)



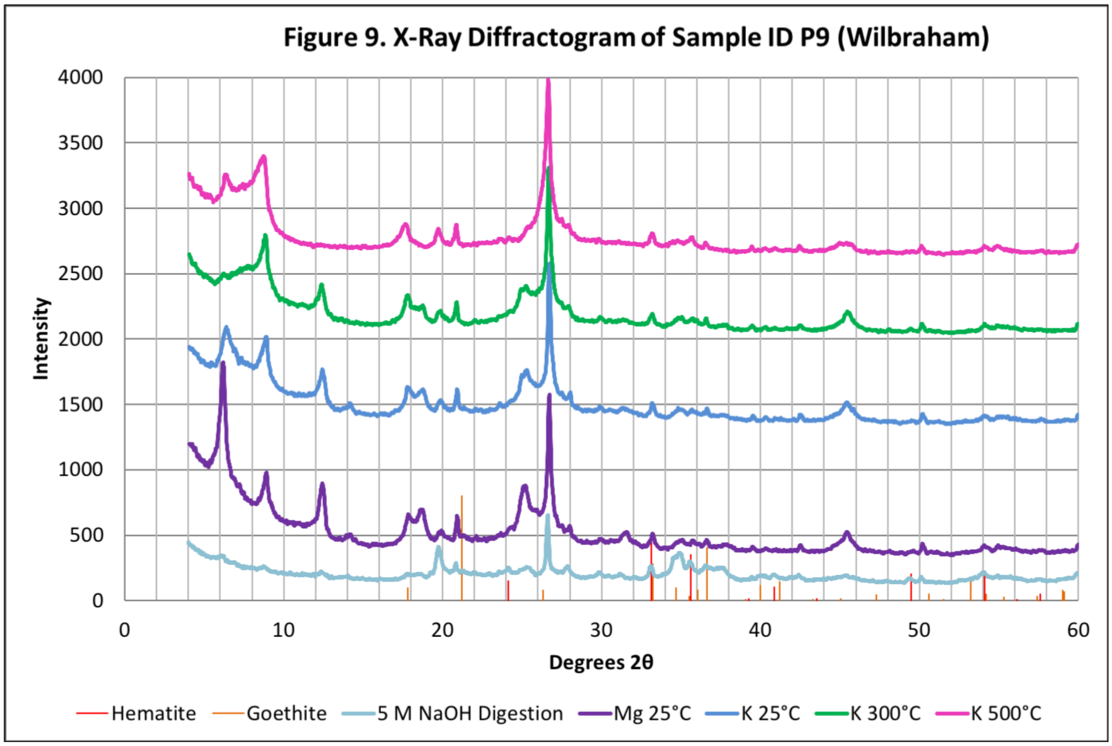


Figure 9. X-Ray Diffractogram of Sample ID P9 (Wilbraham)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

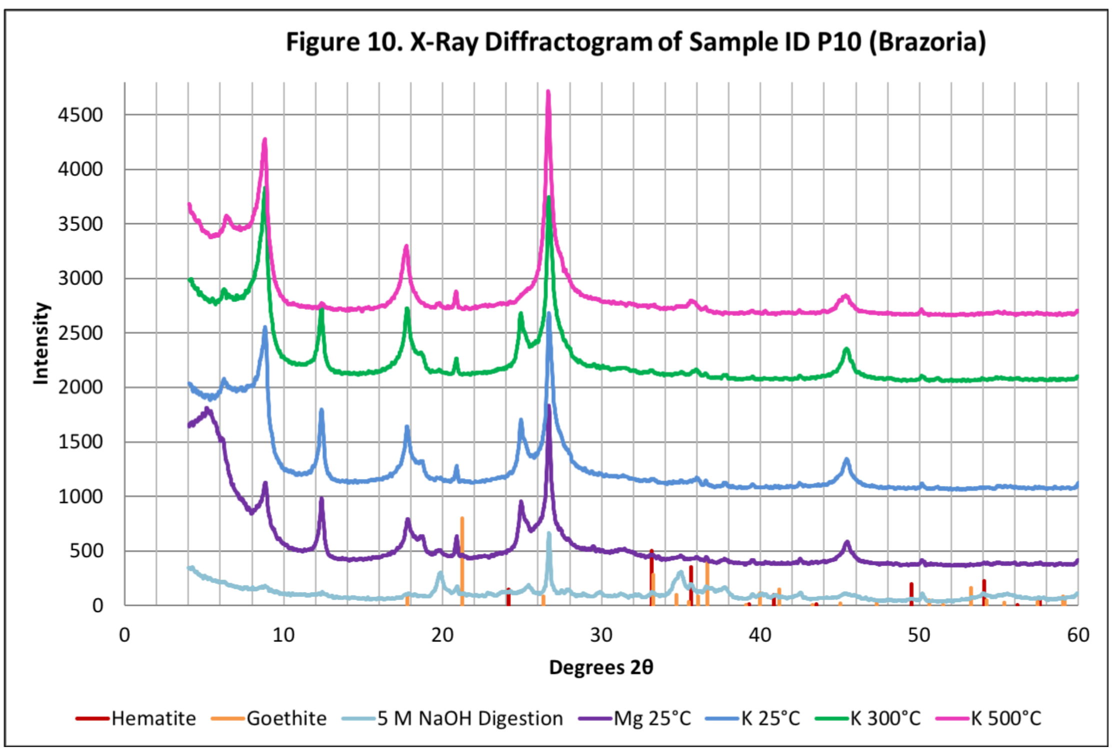
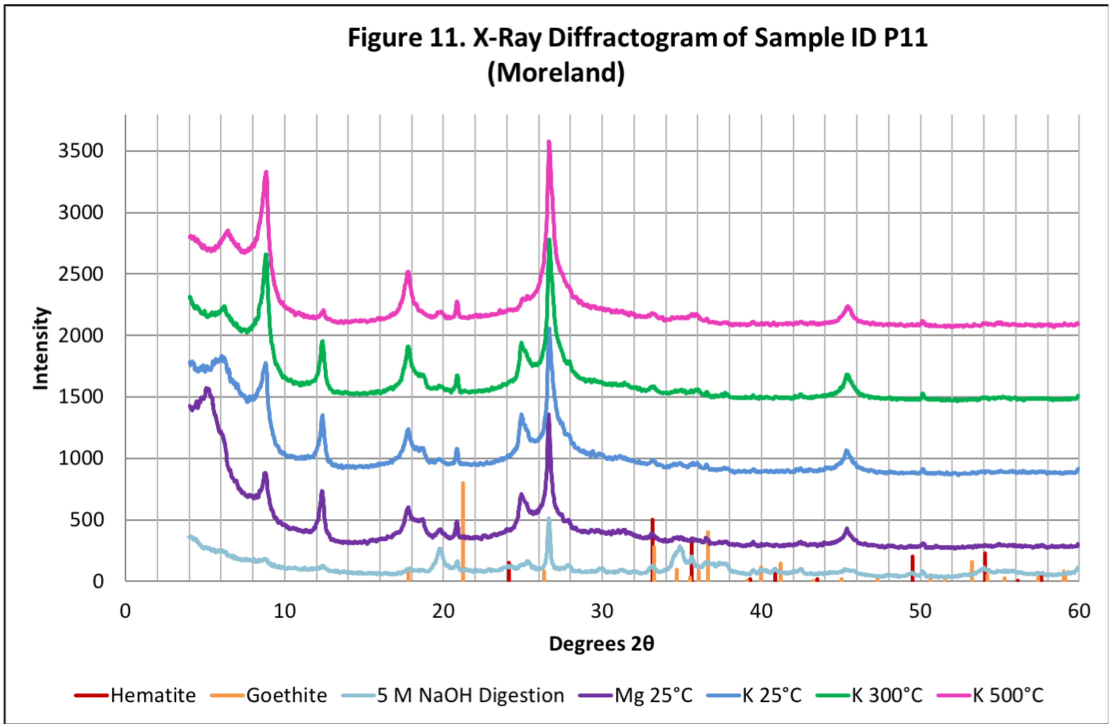
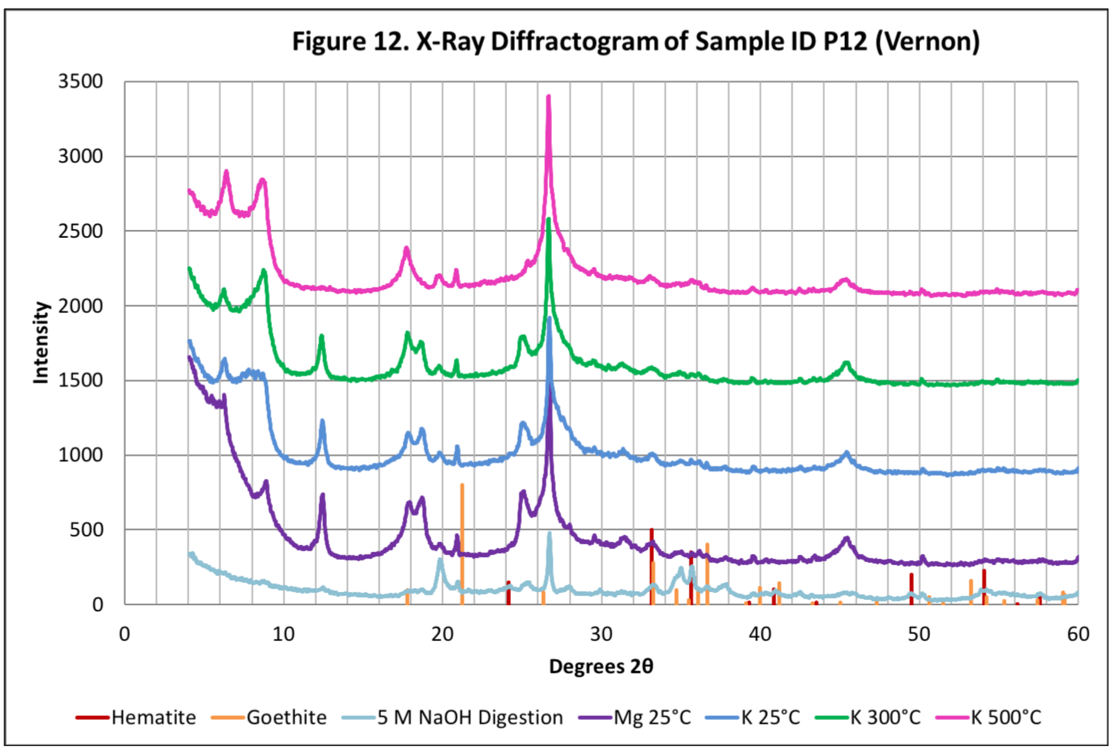


Figure 10. X-Ray Diffractogram of Sample ID P10 (Brazoria)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C





X-Ray diffractograms of non-problematic soil samples.

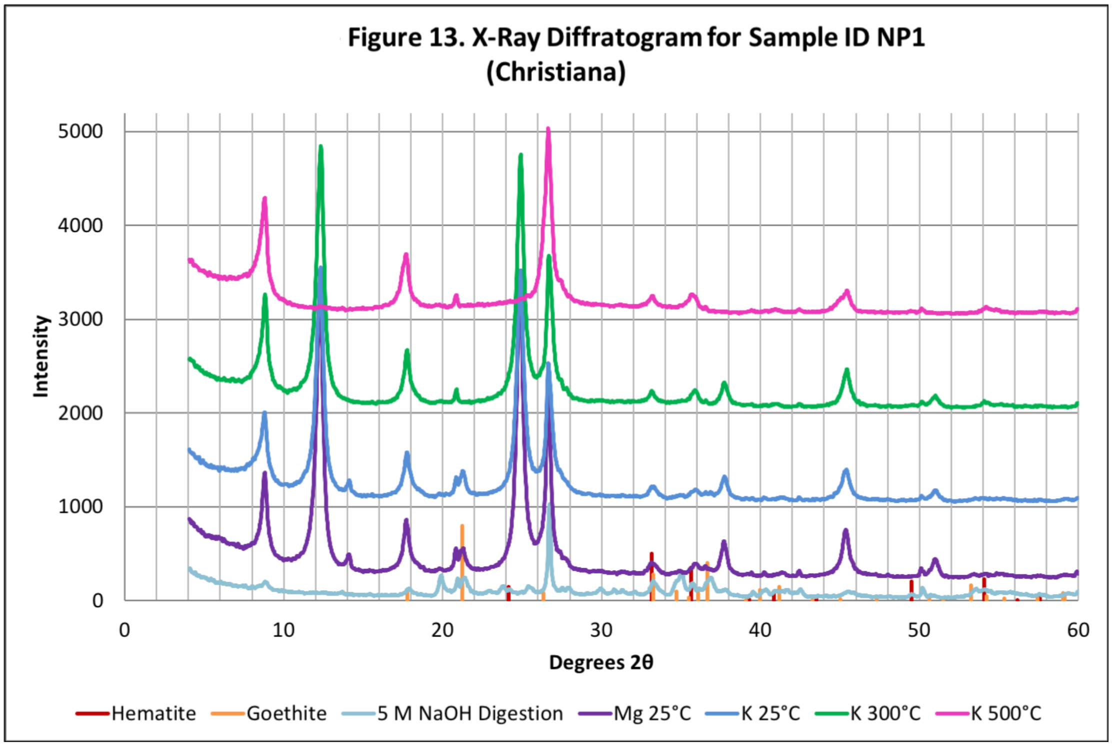


Figure 13. X-Ray Diffratogram for Sample ID NP1 (Christiana)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

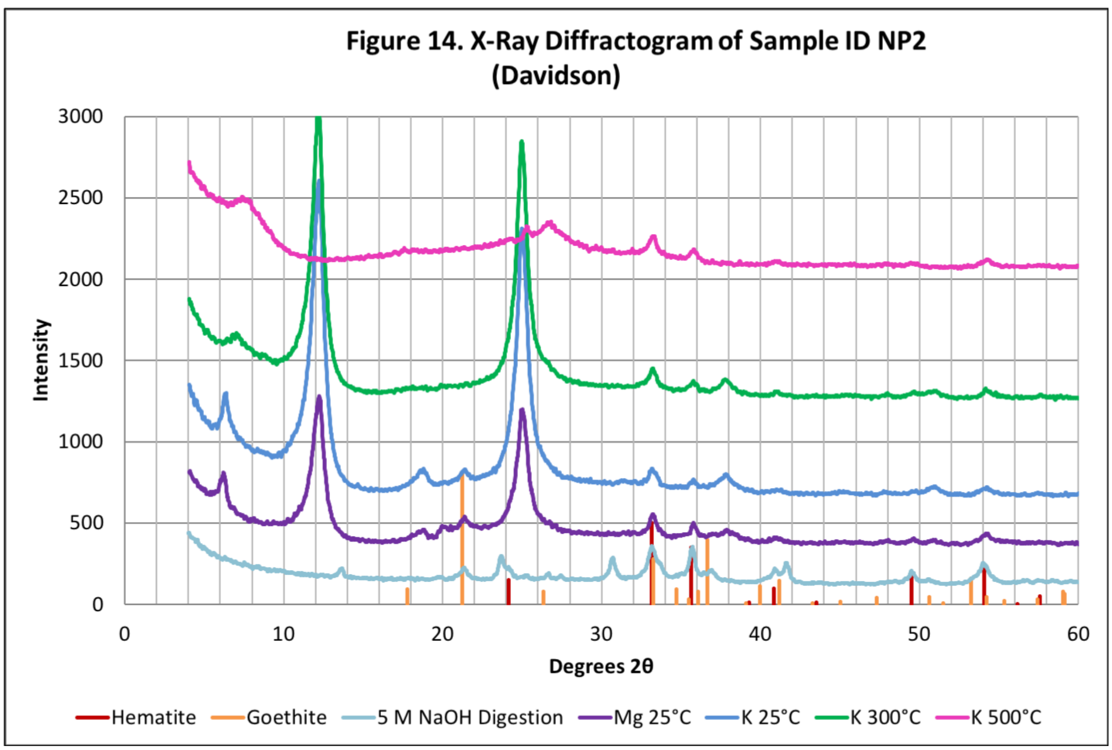


Figure 14. X-Ray Diffractogram of Sample ID NP2 (Davidson)
Intensity
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

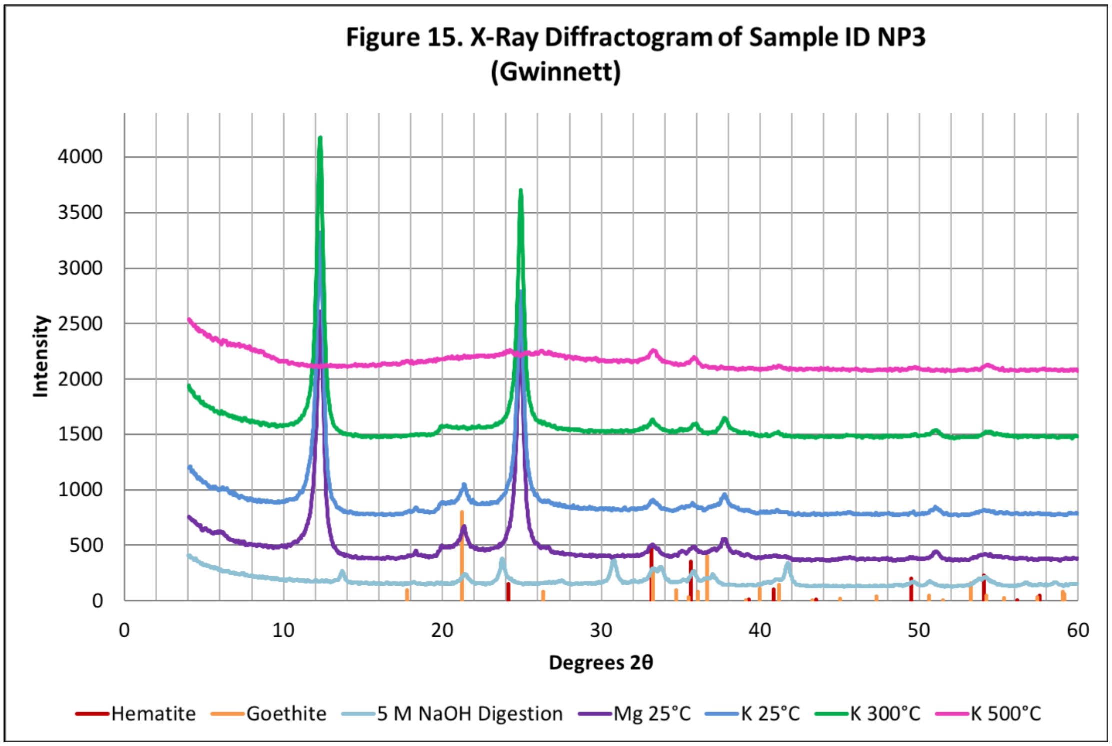


Figure 15. X-Ray Diffractogram of Sample ID NP3
(Gwinnett)
Intensity
0
500
1000
1500
2000
2500
3000
3500
4000
0
10
20
30
40
50
60
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

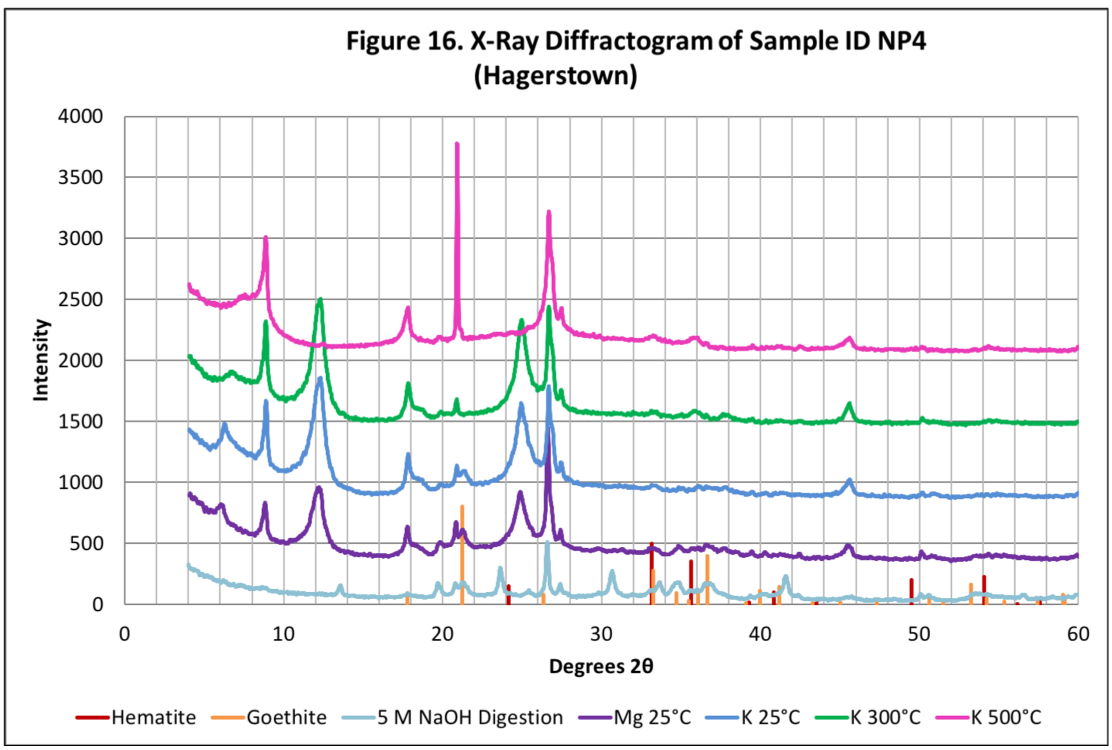


Figure 16. X-Ray Diffractogram of Sample ID NP4
(Hagerstown)
Intensity
0
500
1000
1500
2000
2500
3000
3500
4000
0
10
20
30
40
50
60
Degrees 2θ
Hematite
Goethite
5 M NaOH Digestion
Mg 25°C
K 25°C
K 300°C
K 500°C

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